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London 1849

PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

CORPS OF ROYAL ENGINEERS.

VOL. X.

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DOUBLE BRIDGE ACROSS THE SUTLEJ AT HUGGUR MARCH 1846

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M.DCCC.XLIX.

CONTENTS.

LIST OF PLATES.

*** The small figures in the Map indicate the several estates on the island, of which an official list is given in the Appendix No. II., with the names of the proprietors and the number of acres in cultivation.

WOOD ENGRAVINGS—ILLUSTRATIVE DIAGRAMS.

INTRODUCTION.

The Editors of the 10th volume of Professional Papers have endeavoured to fulfil the resolutions of the Corps Meeting held in February, 1847, of rendering this work adapted to general reading, and to exclude such matter as may be considered purely applicable to the Corps and Military Departments of the Army, the latter appearing in an octavo form, entitled 'Corps Papers.'

The contents of this volume will perhaps be deemed more interesting than various, and some of the Papers may serve to avert the anti-military feeling which now prevails; but whether a large effective force is maintained, instead of a small one of defective organization, for the purpose of reducing the Army Estimates, will depend principally upon the good sense of the public.

There is one point, however, which *economists* should bear in mind, and adopt as an axiom,—that the regular soldier is the cheapest and best description of force in this country, where labour is dear. Hence some pains has been taken, in the second article of this volume, in suggesting an augmentation of the army, rather than the formation of militia, volunteer, or local forces, which are the most expensive, inefficient, and unsuitable to the habits and inclinations of the English people; and as none understand so well the division and economy of labour, they should learn that soldiering is a trade not to be otherwise acquired than by a regular course of instruction during a period of at least two years.

It is conceived too, that the perusal of the outline of the 'Campaign on the Sutlej,' in 1845-6, together with the unpublished dispatches, &c. annexed to the Paper, will enable the reader to form a just estimate of the value of the raw material, as compared with the manufacture and final worth of the soldier when brought into use, and that his valuable services in the field will be deemed a full compensation for the expenditure incurred.

The Editors beg to observe that they have now absorbed all the Contributions to the Professional Papers up to the present date.

G. G. Lewis, Colonel, R. E.
J. Williams, Captain, R. E.

January, 1849.

PROFESSIONAL PAPERS.

I.—*Memoir of the Professional Life of the late Lieut.-Col.* Brandreth, *R. E.* *By Colonel* Lewis, *R. E.*

Since the publication of the ninth volume of this work, the Corps, as well as the Profession, have to regret the loss of the late Lieut.-Colonel Brandreth, who was removed suddenly from this world on the 20th February, 1848, by a rupture of a vessel in the brain. The subject of this Memoir entered Woolwich Academy in 1809, and obtained his commission in March, 1813. He became a Captain in March, 1830, and Lieut.-Colonel in September, 1847. His early services were on the coast of North America, where he served with the expedition under Lieut.-General Sir J. Sherbroke, until the peace. From June, 1816, to November, 1824, he was employed in the West Indies, to which country he returned on a particular duty intrusted to him until 1828. In 1829, Lieut.-Colonel Brandreth was sent to the Island of Ascension on a special mission, which occupied his time until 1831. In 1832 he had an opportunity of being present at the siege of Antwerp; and in 1834 to 1835 he was appointed on a commission to St. Helena, to take over that colony from the Honorable East India Company, and, with his colleagues, created a new government and officers; and on the 20th November, 1837, he was seconded for civil duty.

Lieut.-Colonel Brandreth's services were divided into two periods,—twenty-four years on military duties, and ten years in a civil capacity: of the latter, he was chiefly employed in the Admiralty, as Director of Civil Architects and Engineers in the several naval establishments, although some months previous to his death he received the high appointment of Commissioner in the Board of Railways.

The ordinary duties of an Engineer Officer in the colonies seldom afford opportunities of bringing himself into notice in time of peace; and it was not until 1824, when, the Duke of Wellington being then Master-General, he was sent to the West Indies[1] to carry out the project of Major-General Sir Charles F. Smith, of erecting barracks, the materials being of iron, intended to resist the force of hurricanes: a description of these barracks is given in the second volume of 'Professional Papers.' In this service, Colonel Brandreth appears to have acquitted himself with great credit, and probably elicited talents which led to his future success. On his return to England, in 1828, Sir Charles F. Smith, then Chief Engineer in the West Indies, reported as follows to the Inspector-General of Fortifications.

"Barbados, 22nd September, 1828.

"It was some time doubtful whether the health of Lieut. Brandreth would admit of my seeing him after the completion of the hospital at Antigua, and prior to his embarkation for England, in obedience to your orders. Fortunately, however, I have had that advantage, by which I am enabled to report that the iron-work has succeeded beyond my most sanguine expectation. In an experimental work, it would be hard to expect that perfection in all the most minute details should be stumbled upon in the first suggestions; hence some trifling deviations from the original drawings were found by Lieut. Brandreth, who superintended the castings, to be essential to the practical application of our propositions, and some few improvements still remain to be brought forward.

"The object of the mission upon which I sent Lieut. Brandreth, in October, 1824, being now completed, I trust you will have the goodness to make known to the Master-General and Board, that when I intrusted a question of so much importance and private solicitude to the hands of this Officer, I did so from a conviction that his professional talents were of the highest order, and that his attachment to the Corps would induce him to bestow undivided attention towards the accomplishment of my wishes. I have now merely to add, that the result has more than justified my anticipations; and that I beg, in consequence, most humbly to recommend him to the notice of His Lordship."

The following extracts from a Report of (then) Captain Brandreth, dated July, 1830, afford useful information respecting the construction of barracks in tropical and other climates where marsh miasma prevails:

"In addition to the authority quoted by Dr. Arthur, there are also several other

[1] During the services of Lieut. Brandreth in the West Indies, he was Military Secretary to Sir Charles Maxwith.

medical authorities that appear to favour this Officer's suggestion. Cases are adduced where the interposition of a screen of vegetation between a building and a wind passing over a marsh has arrested the noxious effluvium and prevented disease. Vegetable screens are not encouraged, because, by their decay and decomposition, they themselves generate marsh miasma. The well-known fact of travellers protecting themselves with veils while crossing the Pontine marshes, may perhaps not be unworthy of notice; and the following, mentioned to me by an Officer of H. M. Navy, would appear to bear intimately on the subject."

"The crew of a ship of war lying in English Harbour, Antigua, was attacked with the disease generated by a marsh in its immediate neighbourhood; the windward ports were kept open during the early stage of the sickness, but as they admitted a current of air too strong for the patients, they were covered with bunting, and the disease is said from that period to have been mitigated, and soon altogether subsided. I consider that another and distinct advantage may arise from the adoption of the gauze blinds. Many of the barracks and hospitals in the West Indies are on elevated positions, and exposed to the trade-wind, which blows with considerable force."

"I have examined several specimens of wire gauze, and would recommend that which has the mesh or interstice $\frac{1}{17}$th of an inch square; but as all the buildings in the West Indies are exposed to the immediate action of the sea air, I recommend that copper wire should be used in preference to that of iron."

"Before I close this Report, I beg to recommend the following suggestion, which has the full concurrence of Sir Charles Smith and Dr. Arthur, as both Officers have adverted to the subject in correspondence with me.

"The very first consideration of every individual, in going out to a tropical country, is to procure a mosquito net, to protect himself at night from the insects; and so general is the use of this net in the West Indies, that Africans as well as Europeans of almost every class appear to consider it as a primary and almost indispensable want. In many parts of the West Indies, the sleep of the European soldier is broken by the tormenting stings of the mosquitoes. The comfort, or perhaps, more justly speaking, the necessary want of the mosquito net, has never been yet granted to the soldier in the West Indies, either in the barrack or hospital. If it were adopted occasionally in the former building, I consider it would tend much to prevent fever, and in the latter, should always form part of the hospital bedding, inasmuch as sleep or tranquillity, or the absence of any external cause of annoyance or irritation, are as indispensable to the patient as ventilation or cleanliness for hospital discipline."

ISLAND OF ASCENSION.

The useful services rendered by the subject of this Memoir in the West Indies, no doubt, recommended him for the appointment, under the orders of the Admiralty, to report on the establishment at the Island of Ascension in 1829; and, according to instructions which he received from that Board, with permission of the Master-General, he proceeded to that island, to make a general survey for the proposed course of the water from the springs to the tanks,—to exhibit on the maps all such tracts of land as appeared fit for culture,—to report on the climate and produce,—to take into consideration the defence of the island,—and to suggest what additional works were necessary for its security.[2]

Lieut.-Colonel Brandreth has left two documents, which have been published, explanatory of his operations, and descriptive of the Island of Ascension; first, in the fifth volume of the 'Journal of the Royal Geographical Society of London' (1835), and subsequently, in the fourth volume of this work, published in 1840. Among his papers the following appears:

"When the first adventurer to this wild spot explored his way over a wide plain of cinders and ashes, where no drop of water,[3] and scarce one evidence of vegetable principle, could be discovered,—when he laboured up the steep and rugged mountain, and when he looked on the scathed and withering aspect of the scene spread in awful solitude around him,—he would have condemned the spot to hopeless sterility, and regarded the sea-fowl that settled on the dark red hills as likely to remain the sole and undisputed inhabitants of these arid regions.

"There are, doubtless, many living, who must have visited the island when it was in this primitive condition; and among the number, probably the distinguished Officer (Sir George Cockburn) who gave the first impulse to all those measures that have caused the desert to yield up its fruits, and the depth of the earth its waters; and I think those who, under such circumstances, may chance to revisit the island, will be sensibly impressed with the change it has undergone, and the evidences that every where prevail of the industry and energy of the first and present inhabitants."

From recent Reports from Ascension, up to 1847, the island was healthy, the quantity of arable land was increasing, the supply of water, on the 1st of April, 1847, was 501 tons[3] in the tanks, and there were 463 turtles in the ponds.

The population, or rather the strength of the establishment, in 1847, consisted of 119 persons, of whom only three were sick. The quantity of land in cultivation was considerable, and the produce about 15,000 lbs. of vegetables per quarter, consisting of potatoes, pumpkins, and leeks, carrots and turnips, &c.

[2] He returned to Ascension in 1830, by order of the Admiralty, to set on foot the measures which he had suggested.

[3] Which, in 1848, amounted to 1000 tons.

In 1831, the subject of this Memoir was employed as a Commissioner under the Reform Boundary Act.

SIEGE OF ANTWERP.

In the year 1832, Captain Brandreth went to Antwerp, having obtained leave of absence, in order to be present at the siege of the citadel by the French. This was to him an interesting professional study, and accordingly, by favour of the French officers, he was allowed to be present throughout the whole siege; and, on his return to England, he was ordered by H. M. William IV. to proceed to Brighton, to read his notes, having a private audience of the King.

The siege of Antwerp was interesting and instructive to a person who had never been witness to a siege operation, but the journal does not now afford matter of sufficient importance to transcribe. It appears that the citadel, besides its faulty construction, had not received the usual preparations for a protracted defence, such as blindages, palisades, and removal of obstructions at the foot of the glacis, and the armament was deficient: hence, when attacked by an overwhelming force of near 70,000 men and 150 pieces of artillery, with all the appliances of war, the siege operations were no more than a course of instruction to the French army, and strangers who resorted thither. The following extract may be read with interest:

"In estimating the merits of the attack and defence of this citadel, there are several circumstances attending on the whole affair that must have had weight on the occasion. The French troops selected for this service were probably, in physical quality, discipline, and science, the élite of the army. They were considered to have been equipped in the most complete manner, and advanced to the investment of the place through a friendly country, from whom supplies, in case of emergency, could be readily and amply obtained. The dispositions of the ground afforded favourable cover to their operations, and the soil yielded easily to the workmen. The materials usually required from the immediate neighbourhood of an attack were promptly obtained, and the weather, though not always good, was not altogether unfavourable. The casualties of the besiegers amounted to about 900 men killed and wounded.

"On the 3rd day after the capitulation, I had an opportunity of examining the citadel: the whole of the buildings in the terreplein, or interior, not bomb-proof, were destroyed, and the ground ploughed up in every direction by shells; but the defences and traverses were little injured. The garrison consisted of about 4500 men, with bomb-proof cover for one-half, and the loss sustained was not severe."

The siege of Antwerp is now a mere matter of history, as the concluding scene to the revolution of 1830, and of little military interest: as regards the casualties in the attack and defence of places, except where the breach is assaulted, and sorties are frequent, which is rarely the case with small places, they are generally trivial, if there is a competent supply of bomb-proof cover.

In sieges, by a judicious distribution of the troops, particularly in the defence, a small proportion of the garrison is exposed during the day, and those are the artillery and their assistants in working the guns, and the marksmen spread along the parapets and covert-way to keep up a musketry fire. At night the fire of the artillery generally ceases on both sides, and one-third of the garrison, or more, as the besiegers' trenches approach the place, are placed ready to repel any assault or attempt to surprise; so that, as before observed, it is only when sorties are frequent, or the breach defended, that a great loss in killed or wounded is the result of a siege operation carried on scientifically. In an *attaque accéléré* or *brusque*, and with insufficient means, the consequences are very different; and hence the loss in our sieges in the Peninsula, which were carried on with little means.

1833.—Captain Brandreth was sent by a Committee of the House of Commons to revise the boundary of the borough of Hertford, for which he received a letter of approbation.

In 1834 he was appointed a Commissioner, in conjunction with Mr. Walpole, a Barrister, by the Colonial Office, for reforming the entire establishment at St. Helena, previous to the island being taken over from the East India Company by H. M. Government.

In 1835-6, Captain Brandreth was employed on the Reform Commission in England and Ireland, and upon the improvement and the transport of Irish convicts, for which latter service he received the thanks of Lord Morpeth; and in 1838 he was offered the government of South Australia, by Lord Glenelg, which he declined.

PERMANENT EMPLOYMENT UNDER THE ADMIRALTY AS DIRECTOR OF THE ARCHITECTURAL AND CIVIL ENGINEERING DEPARTMENT.

1838.—The resignation of Mr. Taylor, Civil Architect of the Navy, at the end of 1837, induced the Admiralty to place this branch of that Service upon a better footing: Captain Brandreth was offered the appointment under the new constitution, for the purpose of taking charge of the works in the

Dock and Victualling-yards, to be stationed in London as head of the department, and in immediate communication with that Board. The duties of this office, in connection with the out-ports, necessarily produced an extension in the newly established department, and the appointment of other Officers of Engineers took place, subordinate to Captain Brandreth; and in fact, an establishment to each dockyard, for the immediate superintendence of all engineering and architectural works not connected with the construction of ships of war, manufacture of stores, or conversion of materials for ship-building.

The following synopsis of the principal alterations and additions to the several dockyards will explain the nature and the extent, as well as the importance, of the duties intrusted to Captain Brandreth as Director of Engineering and Architectural Works; and the strength, beauty, and magnificence of the buildings, wharfs, docks, roofs to the building slips, stores, manufactories, or mills, will give an idea of the skill by which these works[4] were executed under Captain Brandreth and the other Officers of Engineers especially attached to the Admiralty as superintending and executive Officers.

At Deptford, considerable repairs were executed to the double dock and entrance; biscuit machinery; iron roof over slip No. 1; two other slips constructed with iron roofs; iron timber sheds; besides other works in progress.

Woolwich.—The river wall was finished, and the old mast-pond converted into a basin for the repairs of steamers; buildings constructed for manufacturing and repairing of machinery; a dock constructed from the basin, and two from the river; a roof over slip No. 7; saw-mills and machinery; a new boundary wall to part of the yard; new chain cable proving house; marine barracks, with others in progress.

Chatham.—Engine for lead-mills; metal-mills; steam engine and machinery; Nasmyth's steam hammer ditto; boundary wall, &c. &c.

Sheerness.—Machinery to cement-mills; for smithery; for mill-wrights' shop; for Nasmyth's hammer, &c.

Portsmouth.—The principal works executed at this station were, the construction of building slips and iron roofs; saw-mills and machinery; mast store, boat store, and new steam basin; and extension of the dockyard in progress, opened in May, 1848.[5]

[4] Many of these works are shown in the preceding volumes of the 'Professional Papers.'

[5] *Vide* Article No. X. of this volume.

Devonport.—Steam engine and machinery to the ropery; timber sheds; Nasmyth's hammer machinery, &c.

Pembroke.—Four new building slips; saw-mills and machinery; reservoir; steam hammer and machinery; timber pond; iron timber shed; and extending the dockyard.

Gibraltar.—Rebuilding naval officer's residence, and other works in progress.

Malta.—Extension of the yard; new dock and coal vaults; boundary wall; iron mast and spar store-house; new anchor wharf; coal stores; bakery; and extension of victualling-yard.

Bermuda.—Completing the breakwater, and houses for artificers.

In addition to the foregoing works, general and particular repairs had been executed throughout the several victualling-yards, naval hospitals, royal marine barracks, naval yards, and packet stations, both at home and abroad.

One of the most important considerations which engaged the attention of Captain Brandreth, as Director of Works, was the gradual substitution of incombustible for combustible materials, having found in the dockyards many temporary wooden and canvass buildings, for which he was desirous of gradually substituting those constructed of iron, zinc, slates, and tiles; and that sheets of corrugated iron should be supplied to the yards for temporary buildings when required.

During the period Captain Brandreth was Director, he had visited all the foreign yards, which enabled him to travel in America, Naples, and Sicily.

The formation of a Railway Board under a Commission, induced the Government to offer Captain Brandreth an appointment in that Commission, and his resignation of the situation as Director of Engineering Works under the Admiralty was the consequence. This led to the following minute of that Board:

"Admiralty, 11th Nov. 1846.

"My Lords cannot receive the resignation of Captain Brandreth without expressing their sense of the services which he has rendered to this department since his appointment in 1838, as Director of the Architectural and Engineering Works of the Admiralty. The great works commenced under his superintendence at Portsmouth and Keyham, and the systematic improvements effected in the dockyards at home and abroad, will remain as honorable proofs of the perseverance and energy with which the powers intrusted to him have been exercised.

"Serving under three successive Boards of Admiralty, Captain Brandreth has enjoyed the confidence of all; and my Lords, in giving to him this last testimony of their approbation, cannot use stronger words than those employed by their predecessors, namely, that the public never had a more useful or a more meritorious servant.

(Signed) "H. G. WARD."

"December 2nd, 1846.

"It is due to the meritorious Officer in question, to make known to the corps of which he is so distinguished a member, that his valuable services are so highly appreciated, and so justly eulogized by my Lords of the Admiralty.

(Signed) "ANGLESEA,
"Master-General of the Ordnance."

The private communications which Captain Brandreth received from his friends in and out of office, and from his brother Officers serving under him in the dockyards, were even more gratifying to his private feelings, and evinced the esteem and respect of those persons, in a high degree, employed under the Admiralty in the supply of machinery, &c., for the dockyards.

In October, 1846, Major Brandreth was offered, by Sir Charles Wood, an appointment in this Board, which led to his removal from the Admiralty, as before explained, and previous to which he received a note from Lord John Russell, couched in the following flattering terms:

"Downing Street, Oct. 13th, 1846.

"Dear Sir,

"I understand from the Chancellor of the Exchequer, that you are willing to accept office as one of the Railway Board. As I presume this to be your wish, I only write to say that I shall be happy to submit your name to Her Majesty as one of the three paid members of the Commission.

"I remain, &c.

(Signed) "J. RUSSELL.

"Major Brandreth."

The Board of Commissioners of Railways was instituted under an Act of Parliament which was passed at the end of the session of 1846, in compliance with the recommendation of both Houses.

The following extract from the first Report of the Commissioners will explain the nature of the duties intrusted to them:

REPORT.

"TO THE QUEEN'S MOST EXCELLENT MAJESTY.

"We, your Majesty's Commissioners of Railways, have, in compliance with the recommendations of Committees of both Houses of Parliament, and in conformity with the practice of our predecessors, the late Railway Department of the Board of Trade, prepared the First Annual Report of our proceedings, which we beg humbly to lay before your Majesty.

"The Report includes a period commencing on the 9th of November, 1846, when we entered on the duties of our office, and terminating on the 31st of December, 1847."

The subjects extracted from the Report are:

I. Accidents on Railways.
II. Statistics and Returns.
III. Railway Legislation.

"I.—ACCIDENTS ON RAILWAYS.

"One of the most important duties assigned to the Commissioners has been that of inquiring into the causes of accidents on railways. These inquiries have been found to be most useful, not only by acting as a check upon the conduct of the officers and servants of Railway Companies, but also from the means which they have afforded of collecting valuable information with respect to the working of railways, which might lead to suggestions calculated to increase the safety of railway travelling.

"It will be seen that the returns of accidents appended to this Report[6] have been prepared in the form which was adopted by the late Railway Department of the Board of Trade. The proportion of the number of accidents to the number of passengers conveyed does not afford, in all instances, the best measure of the safety of railway travelling. For such accidents as occur at stations by getting in or out of a train, it is justly adopted; but for collisions, the number of miles run by the trains, and for accidents occurring to engines, the number of miles run by the engines of each Company afford the proper means for comparison. This information, however, the Commissioners have not been able to procure, and the returns consequently have their former arrangement.

"The returns are divided into two parts; one for the first six months, the other for the last six months, of 1847. The most striking circumstance connected with them is the great reduction in the number of accidents in the latter returns, notwithstanding a great increase in the number of passengers conveyed. At the beginning

[6] For detailed accounts of the causes and results of the several accidents enumerated, the reader is referred to the Appendix to the Report of the Commissioners, printed by order of the House of Commons.

of the former period, 3036 miles were opened for traffic; at the end of that period, or the beginning of the latter, 3496 miles were opened; and at the end of the latter period, passengers were carried upon 3816 miles of railway;—and it appears from the returns that the number of passengers conveyed in the former period was 23,119,412; in the latter, 31,734,607, being an increase of 37 per cent. Yet the number of passengers killed and injured by causes beyond their own control is less by 29 per cent. in the latter than in the former period; and the whole number of accidents to passengers, servants of companies, trespassers, and others, is less by 8 per cent.

"The Commissioners have endeavoured to obtain Reports of all accidents of a nature likely to be attended with injury to the public, whether such injury in the particular cases actually occurred or not. The whole number of such accidents reported during 1847 was 330; and in 22 cases they have considered it necessary to order investigations to be made by their own Officers.

"These accidents may be conveniently arranged under the following heads:

1. Accidents caused by engines or carriages leaving the line.
2. Accidents caused by the breaking of axles or of tires.
3. Accidents by collision.
4. Miscellaneous accidents.

"1.—*Accidents caused by Engines or Carriages leaving the line.*

"Of this first description of accidents it appears that 20 cases were reported to the Commissioners during 1847. In 5 cases, carriages only ran off the line; in 15, the engine left the rails. In several of them, however, the engines or carriages appear most probably to have left the line in consequence of a previous accident of another description, as the breaking of an axle or a tire; but in others the cause has not been satisfactorily accounted for.

"On the 21st February an accident of this nature occurred to the mail train from Hull, on the Hull and Selby Railway, by which two passengers were killed, and eleven passengers and four servants of the Company were injured. The train consisted of eight passenger carriages, a luggage van, and four fish waggons,—the van and three of the fish waggons being in front, the fourth in the rear of the train. It was drawn by two engines, which do not appear to have been closely coupled together, and which were of different sizes; that in front being of 14 tons weight, and having driving wheels 5 feet 6 inches in diameter, and the second engine weighing 22 tons, and having two pair of six-feet wheels coupled: the latter engine and some of the carriages, but not those immediately following the engine, left the rails. The Report made by Captain Coddington will be found in the Appendix. He attributed this accident partly to the mode of connection of the two engines which were not closely coupled; partly to the oscillation likely to be produced by the construction of one of the engines, and to the probability of these effects being increased by a difference in the size of the driving wheels of the two engines; and partly to the permanent way, (which had been laid seven years), being insufficient to bear the action of such powerful engines as one of those referred to. There were other points to which the attention of the Railway Company was requested by the Commissioners, but those which have been mentioned appear to possess the greatest interest, and to be best deserving of consideration.

"An accident of this description, which occurred on the 31st of May, upon the Brighton and Chichester Railway, excited much public interest at the time. In this instance, the engine left the line and was overturned, the engine driver lost his life, and the fire-man was severely injured; but it does not appear that any of the passengers were seriously hurt. The Commissioners, in consequence of communications addressed to them by the local authorities after this accident, thought it right to direct the whole of the engine-stock of the Company to be inspected, and, with the consent of the Admiralty, they, for this purpose, associated Mr. Murray, an experienced Officer in the Steam Department of the Navy, with their own Officer, Captain Coddington. These gentlemen were requested to report particularly as to the number of engines available for the passenger traffic of the Company; the number required to be in steam daily, and their disposition; the daily train mileage of those engines; whether any, and how many of the engines in steam at the time of their inspection ought to have been in the repairing shops; how many were at that time available to supply sudden casualties; whether they considered the number in steam daily sufficient for the due performance of the traffic; whether the number in possession of the Company was sufficient; and lastly, whether there was any thing in the character of the engines which could be considered objectionable, and affecting the public safety. The Report, containing in detail their opinions upon these several points, will be found in the Appendix. On receiving and considering that Report, the Commissioners directed the Company to be informed, that they should not consider themselves justified in sanctioning the opening of any further portion of the lines belonging to the Company, until they had been satisfied that the number of good engines in the possession of the Company was sufficient to supply the requirements of the traffic on every occasion. And it will be seen by the Report of Captain Simmons, on his inspection of the Keymer Branch, which is also given in the Appendix, that this subject was particularly referred to him, and was considered by him on this occasion.

"The Report of Captain Coddington on the accident on the Hull and Selby Railway, and also the joint Report of that Officer and Mr. Murray last mentioned, have caused the attention of the Commissioners to be directed to the question of the security or insecurity of different descriptions of engines. They would be cautious, without ample experience, in condemning any arrangements with regard to locomotive engines which have been approved by Engineers of great eminence and experience; but they have in one instance (that of the Brighton and Chichester Railway) expressed their decided opinion to the Company, that engines of a particular construction should not be used for passenger trains travelling at high speeds; and they have reason to believe that their recommendation has been complied with. They have also, with the view of obtaining further information on this important subject, directed their Inspecting Officers to observe the extent to which different descriptions of engines are employed, and to inform themselves, as much as possible, on the relative effect of the different arrangements which have been objected to in producing unsteadiness, and consequent insecurity; and particularly on the effects of different dispositions of the cylinders, and distributions of the weight upon the wheels of an engine.

"Another accident of this class, which should be mentioned in this Report, is that which occurred on the Lancashire and Yorkshire (late Manchester and Leeds) Railway, on the 16th September, by which two passengers were killed. In this instance, the last carriage of an express train, being that in which these passengers were seated, left the rails, and was dragged a considerable distance before the engine driver was apprised of the circumstances. This case appeared to the Commissioners to require investigation by one of their own Officers. On receiving the Report of Captain Simmons, who attributed the accident to the imperfect state of the permanent way, at the place where it occurred, and to its insufficiency to bear the action of powerful engines at high speeds, they considered it their duty to direct the same Officer to inspect the whole line of railway from Manchester to Normanton. It appears from his Report, after making such inspection, that a large proportion of the road was in an unfit state to bear the powerful engines which the Company were adding to their stock; and that it was necessary to urge the Company to make exertions to provide for the public safety by relaying immediately the weak parts of the road, which was accordingly done.

"Among the Reports which, having been considered to contain matter of public interest, are inserted in the Appendix, there is one which may be referred to under this head, as it is connected with an accident occasioned by an engine leaving the line, which occurred in December, 1846.

"In consequence of memorials from the mayor and town council of Bolton, and from certain magistrates in the county of Lancaster, the line and working arrangements of the Manchester and Bolton Railway were ordered to be inspected and reported upon in January, 1847, the attention of the Inspecting Officer being directed also to the circumstances likely to be connected with the accident above mentioned. The statements contained in Captain Coddington's Report showed that the rails were too weak. This Report, and that already alluded to of Captain Simmons, upon the Lancashire and Yorkshire Railway, give reason to fear that Railway Companies had in some instances overlooked the danger of employing heavy engines at high speeds on lines which were originally laid with rails comparatively light, and at a time when the changes which have taken place in the size and weight of engines, and in the speeds adopted, were not contemplated. It is, therefore, one of the subjects to which attention is required.

"2.—*Accidents caused by the Breaking of Axles or of Tires.*

"With respect to this class of accidents, viz., those occurring *by the breaking of axles, or tires,* 11 of the former description, and 6 of the latter, were reported to the Commissioners during 1847. They have been desirous to obtain Reports of all accidents to trains of a nature likely to produce serious results to the individuals accompanying such trains; but as the law does not require accidents to be reported to them unless attended with personal injury, it is not probable that any accurate judgment can be formed of the actual number of axles and tires broken during the running of trains in 1847, from the number which have been reported. It certainly appears to be desirable, as likely to insure the public security, that every accident of this description should be recorded. The proportions in which such fractures occur on different lines, if truly known, would probably lead to a knowledge of the causes which occasion important differences in those proportions, and particular modes of construction might be approved or condemned on the evidence of the facts collected. At present, there is a very prevalent impression that the action to which railway axles are exposed produces a gradual, but very prejudicial change in the condition of the metal; and a knowledge of the practice which experience has induced the Admiralty to adopt, caused the Commissioners to suggest, in a circular to the different Railway Companies, the propriety of subjecting axles, which had been in use for a considerable time, to the process of annealing.

"3.—*Accidents by Collision.*

"Of these, 37 cases were reported to the Commissioners during 1847.

"By far the most serious of these in its results was the accident which occurred at Wolverton on the 5th June, by which seven persons were killed. A train consisting of 19 carriages, was, by the negligence of a points-man, turned off the main line into a siding, upon which, at a distance of about 540 yards from the points, a coal train was standing. The speed of the passenger train was about 25 miles per hour when it left the main line, and it was not found possible to reduce the speed sufficiently to prevent the serious collision which took place. The accident was clearly attributable to the negligence of a points-man, but there were other circumstances connected with it which are deserving of notice. By the Report of Captain Simmons, it will be seen that the train had only two brakes in addition to those on the tender, and that the whole power to stop the train, although fully applied, could not arrest its progress within 540 yards, although its ordinary stopping place, and that at which there appears to be no doubt that it would have been duly stopped, was only 450 yards further. Several other instances, as will be seen by the Reports of the Inspecting Officers which are appended to this Report, have occured to show that large trains generally are not accompanied by a sufficient number of guards to work the brakes, and that collisions are to be attributed to their deficiency. The Railway Department of the Board of Trade suggested that a brake should be attached to every fourth carriage, and by a royal ordinance of the late Government of France, a similar proportion was enjoined for all trains on the French railways. But it is questionable whether, with the extraordinary speed now commonly in use, even that proportion affords sufficient security. It may be assumed that the same power which can stop a train within a given distance from a speed of 25 miles an hour, would require nearly four times that distance, under similar circumstances, to stop the same train from a speed of 50 miles an hour; and the latter speed is now frequently adopted. To attach a number of guards to every train, duly proportioned to its weight, and the speed at which it is to travel, would, no doubt, cause a considerable increase in the working charges of railways; but the question is too important to be abandoned on such grounds, and requires the serious consideration of every Company.

"In every instance in which, from the Reports of their Officers, a deficiency of brake power has been apparent to the Commissioners, they have pointed out the importance of the evil to the Company; and on the occasion now under consideration they directed Captain Simmons to communicate with Captain Huish, the Manager of the London and North Western Railway Company, with a view to their making some joint recommendation for the public safety which might be generally adopted. This subject is still under consideration; but, without the zealous co-operation of the Railway Companies, the Commissioners can accomplish but little. The most effectual mode, perhaps, of insuring attention to it, is this public statement of their opinion.

"They also requested Captain Simmons to consider two other points alluded to in his Report,—the height and gauge of buffers, and the abolition of facing points.

"It appears that the injuries arising from accidents by collision have, in some cases, been aggravated in consequence of the unequal height of the buffers of contiguous carriages, such irregularity having apparently caused one of the carriages to be thrown up from its place. It has therefore appeared most desirable that the different Railway Companies should be induced to adopt buffers of equal height and gauge; and Captain Huish having concurred with Captain Simmons in a Report to the Commissioners containing this recommendation, they have issued a circular to the several Railway Companies on the subject. The Report and the Circular will be found in the Appendix.

"4.—*Miscellaneous Accidents.*

"Under this head may be mentioned two accidents which occurred in 1846, and which excited much public interest. One of these was caused by the sudden failure of a girder of the iron bridge over the Dee, near Chester, by which five carriages of a train were precipitated from a height of 36 feet, causing the death of five persons, and producing serious personal injury in nine other cases. The other arose from the private carriage of the Earl of Zetland having been accidentally set on fire, in December last, on the Midland Railway between Leicester and Rugby.

"In the case of the Dee Bridge accident, the Commissioners appointed their Inspecting Officer, Captain Simmons, to make a personal investigation on the spot; and they associated with him for this purpose Mr. Walker, the eminent Civil Engineer. In consequence of the Report made by these gentlemen, the attention of the Commissioners was drawn to the question of the necessity for some further inquiry and investigation as to the effect of heavy masses in rapid motion upon the structures intended to support them.

"All who have had occasion to consider the state of our knowledge with respect to the strength of materials, are aware that a multitude of experiments, and the investigations of scientific men, have established the laws on which the relation between the several dimensions of beams of different materials, their stiffness, and their ultimate strength, depends, when exposed to an action not differing in an important degree from a steady load. The experiments necessary for the investigation of this subject were within the means of the individuals who had leisure and inclination to make them; and before our present state of knowledge was attained, numerous structures, which have existed through long periods, afforded a variety of examples for the guidance of Engineers. The failure also of works exposed to the action of weights at rest, or moving with comparatively small velocities, was gradual, and not likely to endanger the lives of individuals without some warning of their insecurity. But the last few years have rendered necessary the construction of a number of bridges, intended for the use of heavy trains passing at great speeds, in designing which, the known laws relating to the strength of materials are most probably inapplicable; while the experiments requisite to ascertain those which may be applicable, are beyond the means of individuals to make; and the highest degree of science will probably be required in combining the results of any experiments bearing on the subject. Neither can the solution of this question be left to time, or to the experience which might be obtained from a number of sudden and frightful accidents; the knowledge is required at once, for the guidance of Engineers who may have to design or to approve such works, of which great numbers are likely to be constructed within a short period. With these convictions, the Commissioners recommended the Government to appoint a Commission, composed of practical engineers and scientific men, to investigate this question, and to endeavour to elicit the general principles by which Engineers may be guided in designing structures to be exposed to the action of great weights moving with high velocities; and more particularly to direct their attention to the application, and to collecting the data necessary for the application, of such principles, in cases where iron was the material to be employed.

"A Commission has been appointed in accordance with their recommendation. The Report, made by Captain Simmons and Mr. Walker on the accident, will be found in the Appendix, together with the minute of the Board recommending the appointment of a commission, and a copy of a circular addressed to the several Railway Companies, suggesting caution in the use of iron bridges.

"The fatal accident which occurred in consequence of Lord Zetland's carriage taking fire, afforded a striking example of the necessity for some means of communication between the different parts of a train being generally adopted by Railway Companies.

"From the Report received by the Commissioners from the Railway Company, it appeared that when about six miles from Rugby a cinder lodged upon the top of the imperial, and burnt through the roof of the carriage; that the carriage was occupied by Lady Zetland and a maid servant; that Lady Zetland retained her seat, but that the maid, being alarmed, threw herself out of the carriage, and was found by the pilot engine, sent back from Rugby to look for her, lying between the rails, about five miles from that station, insensible, and having lost three of her fingers. The Report also states that there were two guards, one at each end of the train.

"This statement was very different from that generally given by the newspapers; and the Commissioners considered, from the reports which reached them from other quarters, that it was a case which required investigation by their own Officers. Captain Simmons was accordingly appointed to make a personal investigation on the spot; and from his Report, which will be found in the Appendix, it will be seen that both Lady Zetland, and her maid, descended from the carriage to the truck on which it was placed, from which the maid appeared to have fallen, or to have thrown herself. It also appeared that the means provided by the Company to prevent accident were very insufficient; that only one guard was attached to a train of 13 carriages, his seat being so placed that he had but a very limited view of the train; and that even if another guard had been present, it is probable, from the construction of the leading brake van, he would have been inside a carriage, and of no use in watching the train. Those who refer to Captain Simmons's Report will perceive that the injuries of the maid servant may probably be attributed in part to the mismanagement of the persons sent back with the pilot engine for the purpose of searching for her; but if the train had been properly watched, and if one of the guards had possessed the means of making a signal to the engine driver, the accident could scarcely have occurred.

"Previously to this accident, the necessity for some means of watching a train, and notifying promptly to the engine driver the occurrence of any accident, had appeared to the Commissioners to demand their serious attention; and in October, after communicating with two of the principal Railway Companies, they caused a circular to be issued, in which the methods proposed to be adopted by those Companies were described, and the Directors of other Companies requested to bestow their earnest attention on the subject, and to try on the lines under their control those means of communication which appeared to them most likely to prove effectual.

"The late Colonel Brandreth, of whose co-operation the Board was so suddenly deprived, gave much of his attention to this subject, in the hope that some additional protection might be obtained for the public. He had interviews with some of the most eminent railway engineers upon the subject, when he consulted with them upon the means which might be adopted, not only for securing the constant watching of trains whilst on their journeys, but also for affording to passengers the means, in case of accident or sudden illness, of communicating with a guard, and for enabling the guard to communicate with the engine-man, for the purpose, when necessary, of stopping the train. Immediately after Colonel Brandreth's death, a communication on this subject was received from the London and North Western Company, explaining the intended experiments of the Company on this subject. On the appointment of Colonel Alderson as Colonel Brandreth's successor, the subject was referred to him, and is now under his consideration.

"The same communication had reference to another subject to which Colonel Brandreth had directed his attention, namely, the practicability of preventing the numerous accidents which at present occur to the servants of Railway Companies in coupling and uncoupling carriages, by the adoption of some safer method than that which is at present in use. This subject is also under the consideration of Colonel Alderson.

"Before leaving the subject of accidents, another Report, which is given in the Appendix, as likely to contain matter of public interest, may be alluded to, although the accidents to the railway works, to which it refers, were fortunately unaccompanied by any other consequence to the public than inconvenience.

"Communications made to the Commissioners respecting the state of the North British Railway, and the uneasiness which appeared to exist in the public mind respecting it, after the failures produced in some of the works by the extensive floods of the autumn of 1846, caused the Commissioners to direct that it should be inspected, and they associated Mr. Walker with their own Officer, Captain Coddington, for the purpose. Their Report describes the state of the works in detail, remarking upon the execution of each, so far as it could be ascertained, by external inspection, and, in some instances, recommending additional precaution for the public security. The attention of the Company was immediately directed to these recommendations at the desire of the Commissioners.

"II.—STATISTICS.

"By the 3rd and 4th Vict. c. 97, certain statistical returns were directed to be made by the Railway Companies to the Board of Trade, and these returns were tabulated by the Railway Department of that Board, and presented to Parliament. Similar returns have been received, tabulated, and presented to Parliament by the Commissioners; and a summary of those for the year ending 30th June, 1847, is given in the Appendix to this Report. The following Table, which brings together the results of these returns for the several annual periods for which they have been made up since 1843, shows the rapid rate at which the amount of railway transport is increasing.

Traffic for Year ending 30th June.	Miles open at the middle of the above periods, or at the commencement of each year.	NUMBER OF PASSENGERS.					
		First Class.	Second Class.	Third Class.	Parliamentary Class.	Mixed.	Total.
1843	1857	4,276,540	11,198,512	6,431,911	..	1,559,933	23,466,896
1844	1952	4,875,332	12,235,686	8,583,085	..	2,069,498	27,763,602
1845	2148	5,474,163	14,325,825	13,135,820	..	855,445	33,791,253
1846	2441	6,160,354	16,931,065	14,559,515	3,946,922	2,193,126	43,790,983
1847	3036	6,572,714	18,699,288	15,865,310	6,985,494	3,229,357	51,352,163

Traffic for Year ending 30th June.	RECEIPTS FROM PASSENGERS.						Receipt for Goods.	Total.
	First Class.	Second Class.	Third Class.	Parliamentary Class.	Mixed.	Total.		
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
1843	1,374,942 0 0	1,288,758 0 0	411,382 0 0	..	35,175 0 0	3,110,257 0 0	1,424,932 0 0	4,535,189 0 0
1844	1,432,688 0 0	1,375,679 0 0	483,609 0 0	..	147,858 0 0	3,439,294 0 0	1,635,380 0 0	5,074,674 0 0
1845	1,516,805 0 0	1,598,115 0 0	651,903 0 0	..	209,518 0 0	3,976,341 0 0	2,233,373 0 0	6,209,714 0 0
1846	1,661,897 0 0	1,937,946 0 0	738,474 0 0	293,732 0 0	93,164 0 0	4,725,215 0 0	2,840,353 0 0	7,565,569 0 0
1847	1,675,759 6 9	2,048,080 6 11½	737,452 5 4	539,976 16 11	146,733 9 1	5,148,002 5 0½	3,362,883 19 6¾	8,510,886 4 7¼

Railway Cost of Construction.

See page 21.

"But these returns afford only a very small proportion of the statistical information connected with railways, which it appears desirable and important for the Legislature to possess; and even with respect to the particular description of information which it may be supposed they were intended to supply, they are defective; and there is no power under the existing law by which the Commissioners can call for additional returns, or alter the forms in use. As now made, they show the number of passengers divided into classes, conveyed by each Company, and the receipts of each Company from their passenger and goods traffic respectively, and afford probably a fair measure of the fluctuations in the amount of business of any particular Company from time to time. The form was evidently prepared with the intention that these returns should afford also a fair comparative measure of the business of different Railway Companies, and of the proportions between the amount of business and the receipts of different Companies; but as the same interpretation has not been given in all cases to the headings of the several columns, they do not completely answer this purpose, nor would they afford, if perfectly made, general information as to the traffic and intercourse between particular places, as between London and Birmingham, Manchester and Bristol, or other important towns.

"With respect to the financial transactions of Railway Companies, these returns afford no information, nor are the Commissioners empowered to call for any; but on considering the large amount of capital already invested in railways, the large amount which will be required within a brief period to complete those which have been sanctioned, and the complicated nature of the financial engagements into which some of the Companies have entered, it appeared to be their duty to endeavour to collect and arrange as much information as possible upon those subjects from the sources available to them. The importance of such inquiries having been felt by both Houses of Parliament, the attention of this Department has been directed to the subject by the orders from Parliament for returns. During 1847, eleven parliamentary orders were sent to the Commissioners, rendering it necessary for them in each case to require returns from the Railway Companies. Of these orders three were from the House of Lords and eight from the House of Commons. Most of these orders relate to the financial transactions of Railway Companies; but one of them has reference to the number of persons employed respectively in the construction of new railways and in working existing lines.

"The general results of the most interesting of these returns are shown in the following Table:

	Length of Railway authorized to be constructed.	Capital authorized to be raised by Shares and Loans for Railway purposes.	Nominal Value of Stock or Shares created.	Amount actually raised.			Length of Railway opened for Traffic.
				On Shares.	By Loans.	Total.	
	Miles.	£.	£.	£.	£.	£.	Miles.
Prior to Dec. 31, 1843	2276	82,848,081	..	43,468,641	22,062,151	65,530,792	1952
During 1844	805	20,454,698	..	4,341,519	2,479,256	6,820,775	196
" 1845	2700	59,479,485	..	15,622,831	506,978	16,129,809	293
" 1846	4538	128,918,207	..	30,856,627	6,958,366	37,814,993	595
" 1847	1354	44,879,739	..	32,173,973	8,851,514	41,025,487	780
	11,673	336,580,210	222,635,668	126,463,591	40,858,265	167,321,856	3816

"And from the return above alluded to respecting the employment afforded by railways, it appeared that on the 1st May, 1847, there were 47,218 persons employed as servants of Companies on 3305 miles of railway in operation, and that 256,509 were employed in constructing railways.

"With reference to the amounts inserted in the above Table, it is necessary to remark that they cannot be given with the precision of which a statement in figures is generally supposed to admit. The first subject to which inquiry is naturally directed, is the amount which the Legislature has authorized to be raised for railway purposes, the Acts of Parliament being referred to for the several authorities; but as these authorities are sometimes loosely stated, as one Act of Parliament is sometimes dependent upon another, and as numerous transfers of powers have taken place, the inquiry is so complicated that no two persons are likely to agree in their results in extracting from the Acts the amounts of capital authorized to be raised under them. In the foregoing Table, the several sums returned are principally derived from the returns made by the Railway Companies.

"In considering the commercial effect of the power to raise capital conferred upon Railway Companies, a very important difference is to be observed between capital authorized for the construction of railways, and that which is employed in purchasing the property of other Companies, or in purchasing land. The former has a direct tendency to increase the demand for labour, and consequently to affect the wages and consumption of a portion of the population, whilst the latter has no such effect. The returns which have been called for do not distinguish these classes of capital; but the distinction, in considering the effect of railway expenditure upon the country, is very important.

"After observing the progress which has been already made with respect to railways, it is interesting to consider what is likely to be accomplished in the present and following years. It may be assumed that at the end of 1847, all the lines authorized previously to 1844 were completed; of 805 miles sanctioned in 1844 there had been 665 miles opened for public traffic, and the remainder were in progress; of 2700 miles authorized in 1845, there had been 786 completed; and of 4538 miles authorized in 1846, there had been 84 completed. From this it appears, that under ordinary circumstances the railways sanctioned in one session of Parliament are completed within 4½ years from the end of that session; that less than one-fifth of the whole require more than 3½ years for their completion, about one-half requiring between 2½ and 3½ years, and the remainder less than 2½ years.

"If it could be supposed that these proportions would continue to be observed, a fair estimate might be made from the length of railway, and amount of railway capital authorized in each session, of the number of miles which will be opened, and the amount which will be expended on railways in each year. Thus it might be expected that in 1848 the remainder of the lines sanctioned in 1844, one-half the extent of railway authorized in 1845, and about one-fourth of that authorized in 1846, or upwards of 2600 miles, would be opened. But it is known that many of the lines authorized in those years are not yet commenced; that at the latter end of 1847, nearly 1200 miles of railway sanctioned in 1846 were not commenced, and a few miles even of the railways authorized in 1845; and, it appears nearly certain that the expenditure necessary for proceeding with the rapidity with which railways have hitherto been constructed, cannot be maintained by the Companies. Under the Act which the Legislature passed in December last, with a view to relieve the country from the effect of a too rapid expenditure on railways, the commencement of about 2230 miles of railway is postponed for 12 months, and applications have been made to the Commissioners for an extension of the time for the completion of 3645 miles, being nearly half of the railways authorized and not completed. It may be considered, therefore, that the rapidity with which the several lines will be completed, will be regulated by the facility with which the Companies can raise their capitals.

"If Railway Companies had experienced no extraordinary difficulty in raising capital during 1847, it may be estimated that their expenditure in that year under the Acts of 1844-5-6-7, would have been about £64,000,000; but it appears that little more than £41,000,000 were raised for railway purposes in that year. And if that be assumed as the limit which their expenditure will be able to attain, it will require four years for them to obtain the capital now authorized, but not yet raised by them. And if this expenditure be maintained, and the capital authorized be sufficient for the completion of the several lines, it may be expected that about 2000 miles will be completed annually during the next four years.

"III.—RAILWAY LEGISLATION.

"The present Board of Commissioners of Railways was instituted under an Act which was passed at the end of the session of 1846, in compliance with the recommendations of Committees of both Houses of Parliament. By this Act the powers which had been previously exercised by the Railway Department of the Board of Trade were transferred to the Commissioners, and additional powers of inquiry were given in case of references made to them by the Crown, or by either House of Parliament.

"It was recommended by the Committees, and it was also announced to be the intention of the Government, that additional powers, beyond those which had been possessed by their predecessors, should in the following session be given to the Commissioners, with a view to the more effectual supervision of the railway system of the country, and for the purpose of assisting the two Houses of Parliament in disposing of that large portion of their business which relates to railways. It accordingly became the duty of the Commissioners, in connection with the Government, to prepare a measure on this subject, which was introduced into the House of Commons early in the session of 1847. The pressure of other public business, however, was such as to prevent the subject being taken into consideration until a period of the session had arrived when it was obviously impossible that the Bill could become law. It was consequently withdrawn, and it was at the same time announced, that another Bill on the same subject would be submitted to the Legislature in the present session. As the question thus remains open for the decision of Parliament, the Commissioners consider it right to take this opportunity of shortly stating some of their views with reference to additional railway legislation.

"The subject may naturally be divided under two heads; namely, 1st, the additional legislation which may be required for the purpose of enabling the Commissioners to assist Parliament in deciding upon and disposing of Railway Bills; and 2ndly, the powers which it may be expedient to confer upon them, for the better supervision of existing railways.

"1.—*Railway Bills.*

"That portion of the Bill of last session which had reference to the former of these heads, did little more than carry out some of the recommendations which had been made by the Committee of the House of Commons of 1846, on Railway Acts Enactments, and of the Committee of the House of Lords of the same year, on Railways. The Commissioners, therefore, in preparing, in concert with the Government, that portion of the Bill, were in fact adopting, and putting into form, recommendations which had been already made to the Legislature. In adopting, however, the suggestions of the Committee on Railway Acts Enactments, the Commissioners thought it right to make two exceptions. The Committee had recommended that the new Board to be established for the supervision of railways should be empowered to decide on all questions as to the compliance with the Standing Orders of the two Houses of Parliament, with reference to Railway Bills. They also recommended that the Board should possess a *veto*, to be exercised only at their own discretion, on every application to Parliament for a Railway Bill. With every disposition to defer to the judgment of the Committee, the Commissioners were not able to concur in this opinion. It appeared to them, that such powers would be inconsistent with the system which has hitherto been adopted by the Government of this country,—that they would be regarded as a serious and objectionable interference with the functions of the Legislature, and that it was the proper duty of an administrative department of the Government rather to advise and assist, than to supersede the deliberations of Parliament. They therefore recommended that no such powers should be inserted in the Bill.

"It is not necessary here to enter into an examination of the details of this part of the Bill; but there are two of its leading provisions, with respect to which some explanation may be desirable.

"1st. It has been a frequent subject of complaint that in times of speculation, schemes for new railways have been got up and brought before Parliament without sufficient consideration. It has sometimes happened that surveys have been made for very extensive lines of railway, and the parliamentary plans and sections deposited, in the short space of a very few weeks. Within such a period it was scarcely possible that due attention could be given to the selection of the best line with a view to the public interests; much less could a proper opportunity be given for consulting the convenience and wishes of individual land-owners. In many cases a land-owner might not be aware that his property was likely to be crossed by the proposed line, until the plans and sections had been actually deposited. Supposing that he were then able to suggest a deviation to the Company, which might avoid some threatened injury to his property, without inconvenience, or even with positive advantage, to the public, he would probably be told that his suggestions, however valuable, were too late, and that the Company had no power of deviating in their Bill from that scheme for which they had deposited the plans and sections. The land-owner would thus be left to the alternative either of submitting to an injury admitted to be unnecessary, or of having recourse to the expensive and troublesome proceeding of a parliamentary opposition to the Bill. In the latter event, the Committee on the Bill might be placed in the disagreeable position of having to choose between the rejection of a scheme which they might consider important for the interests of the public, or the infliction of a private injury which had been proved to be unnecessary. In some cases, it is believed, the object of the land-owner has been attained by entering into a private agreement with the Company, by which the Company have undertaken, on condition of the land-owner's opposition to their Bill being withdrawn, to carry through Parliament, in the following session, an Amendment Bill for the deviation desired. Such an arrangement is, however, liable to the objection that it is something like a fraud upon the Legislature, inasmuch as the Company are, in the first instance, obtaining parliamentary sanction for a scheme which they know to be liable to objections, and which they have no intention of carrying into execution in the form in which it is proposed.

"With the view of remedying these defects in our present system of railway legislation, the Commissioners were of opinion that it was desirable that a somewhat longer time should be required in the preparation of Railway Bills, and also that a better opportunity should be afforded to land-owners of making preliminary arrangements with the Company, as well as of bringing their cases under the consideration of the Committee on the Bill. For this purpose they proposed that, in an early stage of the proceeding, and before the deposit of the plans, the line should be clearly staked out on the ground, so as to show to land-owners and others the course which the proposed railway was intended to take. If any land-owner considered himself aggrieved, and conceived that he could suggest an improvement in the line, it was proposed that the Commissioners should be empowered, on application made to them, to send down an Officer, who should meet both parties, and inspect the two lines on the spot. If the Company were disposed to adopt the suggested deviation, the Commissioners were to be empowered to authorize them so to alter their line in their plans and sections to be afterwards deposited. If, on the other hand, the Company were to decline acceding to the suggestion, but the land-owner should be desirous of submitting the deviation to the decision of the Committee on the Bill, it was proposed that the Commissioners should be empowered to authorize the land-owner to deposit the requisite plans and sections, so as to enable the Committee to decide between the two lines. It was hoped that by these means some security would be afforded, that railway schemes would be more maturely considered before being presented to Parliament,—that land-owners would be better able to make arrangements for their own protection and convenience; and lastly, that Committees on Railway Bills would be put in possession of the means of adjudicating more satisfactorily on the disputed questions submitted for their decision.

"2nd. The other provision of this portion of the Bill on which some explanation may be desirable, is that which relates to the mode of testing the engineering merits of new schemes submitted to Parliament. Under the existing system, this object is effected only by evidence before the Committee on the Bill. It is not supposed that the members of these Committees possess any knowledge of engineering; they have no previous opportunity of obtaining information on the points which are likely to come before them; they are not furnished with any professional advice or assistance; and no means is provided for enabling them, by local examination, to test the accuracy of the statements which may be made before them. It cannot be supposed that the examination of rival engineers, by Counsel, before such a tribunal, can be a very satisfactory mode of obtaining the requisite information as to the engineering merits or demerits of the proposed line. It is certain that such a method of eliciting the truth must be attended with much unnecessary delay and expense; and that it must afford to parties who may have any sinister object in prolonging the inquiry, an opportunity of wasting time, by the discussion of questions which would not be entertained before a competent tribunal.

"With the view of remedying these evils, it was proposed, in the first Report of the Committee of the House of Commons on Railway Acts Enactments, that the new Board proposed to be established for the supervision of railways should inquire into all those engineering questions on which Committees on Railway Bills are now required to report, and that they should report to the House the result of their inquiries, such Report being conclusive on the Committee, who should not be empowered to call for further evidence on the subject. Clauses were inserted in the Bill of last session, with the view of carrying out these recommendations. Under these clauses, it was intended that the inquiry should, in the case of each Bill, be referred to some person possessed of competent engineering knowledge, either a member or officer of the Board, whose duty it should be, in the first instance, to examine the deposited plans and sections, and to make himself master of any other official information on the subject to which he had access. Having thus obtained a general knowledge of the scheme, and having probably directed his attention more especially to the important or doubtful points of the case, he would be the better prepared to meet the engineers of the opposing parties, whom it was intended that he should see, in all cases in the presence of each other, for the purpose of obtaining from them any additional information which he might desire, as well as of enabling them to lay before him such statements and suggestions as they might consider necessary. It is probable that in many cases the state of the facts would thus be ascertained, by means of the admission of the parties; but supposing any question to arise on a matter of fact, it was to be decided either by the production of evidence, or by sending down a competent Officer to ascertain the fact by a local examination. By this means it was hoped that a satisfactory Report on all engineering points might be prepared, which was to be presented to the House, and to be referred to the Committee on the Bill. The Report was to be considered conclusive on engineering points; but in the possible event of an accidental error on a matter of fact, an opportunity was to be afforded to the Committee, on the application of one of the parties, to send the Report back for the re-consideration of the Commissioners, security being taken, by a power of awarding costs, against such applications being made frivolously or vexatiously. There seems reason to hope that by some measure of this kind, Committees might be relieved from a difficult and burdensome duty, and that by transferring this duty to a more competent tribunal, much delay and expense might be saved to the parties, whilst all interference would be avoided with the functions of the Committee and of Parliament as to the final decision on the general merits of the Bill.

"The Commissioners abstain from entering further into a discussion of that part of the Bill of last session which had reference to the proceedings on Railway Bills; but they have thought it desirable thus to give some explanation, with respect to two of its more important provisions; being of opinion that, whatever measures may hereafter be taken for simplifying such proceedings, it will be important that they should include means for insuring a more careful preliminary consideration of new schemes for railways, as well with reference to the interests of the public as to those of land-owners; and also for transferring the inquiry and examination into questions of engineering from Committees of the two Houses of Parliament to a tribunal better qualified, as well by professional knowledge and previous preparation as by its mode of procedure, to deal with such questions.

"2.—*Supervision of Existing Railways.*

"The second branch of the subject of railway legislation, which remains to be considered, relates to the powers which it may be desirable to confer upon the Commissioners of Railways, for the supervision and regulation of existing railways. Under different Acts, from the year 1840 down to the year 1845, limited powers of this kind were conferred by the Legislature upon the Board of Trade. The principal object of these powers appears to have been to promote the public safety; but, in some instances, regulations were adopted with a view to the public convenience, or for the purpose of facilitating the settlement of disputes either between different Railway Companies, or between such Companies and other parties. By the Act of 1846, these powers were transferred to the Commissioners of Railways, and the manner in which they have been exercised has been explained under the previous heads of this Report. Experience has shown that it is in some cases desirable that these powers should be altered or amended; and the grounds upon which such amendments were proposed in the Bill of last year, and are still recommended by the Commissioners, have been stated under the different heads of the *Opening of Railways*, *Bye-Laws*, *Cheap Trains*, and others. These amendments being matter of detail rather than of principle, it is not necessary further to refer to them in this place.

"There remains the question of the expediency of additional measures for the general superintendence and regulation of railways by a Department of the Government, and of the mode in which such superintendence, if desirable, should be carried into effect.

"In considering this subject, it must not be forgotten that all interference of this kind must be regarded as an exception from the ordinary rules which should regulate commercial enterprises, and as requiring to be justified by special circumstances. Although Governments may in former times have imagined that they were able to promote the interests of the public by taking measures for regulating the supply of commodities, and by interfering with the proceedings of private traders and capitalists, it is now generally admitted that such interference was founded upon erroneous principles, and that the interests of the public are best consulted by leaving, in all ordinary cases, supply and demand to be regulated by the principle of competition. Whether we have regard to cheapness, to quality, or to the convenience and accommodation of the public, experience has proved that all these objects are best attained, in all ordinary commercial transactions, by the unfettered operation of the competition of capitalists.

"There are, however, exceptions to this principle. Supposing that the nature of the undertaking is such that it requires the exercise of special powers beyond those authorised by the ordinary law of the country, and supposing also that the Legislature thinks proper to confer those powers only on special conditions, it must be obvious that in such a case some superintending authority may be required for the purpose of securing the due fulfilment of these conditions. An Act of Parliament for the construction of a railway is a case in point. The promoters of such an undertaking, being unable to carry it on under the ordinary law of the country as a partnership or joint-stock company, apply to the Legislature for the privilege of being incorporated by a special Act, in such a manner that the shareholders in the undertaking may be individually liable only for the amount of their respective shares. They also apply for the power of purchasing, without consent, such portions of the properties of a great number of land-owners as may be necessary for the construction of their line of railway and their other works. In conceding these extraordinary powers, Parliament thinks fit to make certain conditions. It is required that the capital authorised to be raised by the incorporated Company shall be limited in amount, and that its application shall be strictly confined to the purposes specified in the Act. It is also required, as a further condition, that certain accommodation should be afforded to the public, and that the Company, in the management of their affairs, should conform to the regulations laid down in their Act, as well as in other general statutes. It is manifest that some controlling authority must be required for guarding against any misapplication of funds, as well as for securing a compliance with the other requisitions of the Legislature. Such interference is, no doubt, an exception from the ordinary rule; but it is an exception which appears to be not only justified, but required, by the special circumstances of the case.

"There are other considerations of greater importance which tend to show that, in the case of railways, the ordinary advantages cannot be expected to be derived from a system of non-interference, and that the principle of competition is not fully applicable to such undertakings.

"When railways were first established, it was supposed that a railway might be the property of one Company, and that the traffic upon it might be carried on by other Companies, or by private individuals, as in the case of canals. Accordingly, by the earlier Railway Acts, the Companies were authorized to take tolls from the parties making use of their lines for their engines and carriages. Had this system been practicable, the principle of competition would have been applicable to railways, with the single exception of the toll payable to the proprietors of the line. But experience soon proved that this mode of conducting the traffic was totally impracticable. The liability to accidents by collision, especially in the case of passenger trains travelling at high speeds, is of itself a consideration sufficient to show the necessity of placing all the trains on a railway under some common management and control. The necessity of obtaining frequent supplies of water and fuel,—of making use of stations, as well for passengers as for goods and engines,—of requiring the services of points-men, police, and others, and of obeying signals, will show still further the impossibility of opening railways to the indiscriminate use of any parties who may choose to run trains upon them. Although in certain cases a second Company has been allowed to make use of a railway, generally for a short distance, and subject to strict conditions as to management, it may now be assumed to be a rule, established by experience, that the working of each line must ordinarily be intrusted to the management of a single Company, and that the principle of competition is not applicable to such an undertaking.

"Admitting that competition cannot be permitted on the same line of railway, it may next be considered whether the same object may not be accomplished by the establishment of competing lines between the same termini. If such a system be practicable at all, it could be applicable only to those very populous districts where the traffic is likely to be sufficiently great to afford a profit to two competing railways. It may be doubtful, however, whether this can be considered a desirable arrangement for the public, unless the traffic be so large as absolutely to require two railways for its conveyance. Considering that the greater part of the expense of conveying each passenger must be regarded as consisting of the original outlay of fixed capital, it must be obvious that the same number of passengers might, with the same profit to the Company, be conveyed much more cheaply on a single railway than if they were divided between the lines of two Railway Companies; and, consequently, that the interests of the public might be more effectually promoted by proper arrangements and conditions with a single Company, than by the establishment of a second railway. But assuming, for the sake of argument, the advantage of competition in such a case, there can be no security for its continuance. The advantages of an amalgamation, or of some other arrangement, between the contending parties, are so obvious that they cannot be expected permanently to maintain their contest, more especially as they are in all probability under no apprehension as to future competition, the prospect of a return from any third line being quite inadequate to its cost of construction.

"Experience has fully borne out these views: there have occasionally been severe contests between competing Companies, and the public have for a time enjoyed the benefit of the consequent low fares; but these contests have usually ended either in an amalgamation between the two Companies, or in some other arrangement between the contending parties, which has put an end to all the advantage derived by the public from the competition. In some cases, where the competition has been less direct, and where the competing traffic has been but a secondary object to the Companies, the effect may have been more permanent, but the advantage to the public has been the less decided.

"It may then be assumed that, although in certain cases public advantage has been, and may hereafter be, derived from the competition of Railway Companies, these cases must be regarded rather as the exception than as the rule, and at all events that the interests of the public cannot safely be intrusted to the operation of the principle of competition in the case of railways, as in that of ordinary commercial enterprises. The railway system must therefore necessarily partake of the nature of a monopoly, and must also be liable to the evils of a monopoly, unless this tendency can be checked by other means. In fact, the more highly we estimate the importance and utility of the invention of railways, the more liable must it appear to those evils, inasmuch as the control of a Railway Company over any line of communication is more complete in proportion to the superiority of railways to all other means of conveyance. It may be true that the evils arising from these monopolies may not appear to have been so great as under the circumstances might have been anticipated. This may be attributed in part to the circumstance that these undertakings have hitherto been in general under the direction of persons of high character, who were disposed to show a deference to public opinion, and to take an enlightened view of the permanent interests of the Companies over which they have presided. But it may perhaps be ascribed still more to the fact that the evil would be experienced, not so much in the shape of any direct injury or positive loss, as in that of the public being deprived of a portion of that advantage which they might otherwise have received. The introduction of railways must, under almost any system of management, have been a great public benefit; but the question is whether, in consequence of the want of due control, the public have been deprived of any portion of that benefit which would otherwise have accrued to them. Although this is a subject with respect to which the public can scarcely possess adequate means for forming an opinion, experience has shown that they are keenly sensible of many of the abuses of the present railway system, and more especially of the want of any remedy by means either of competition or of an effectual superintending control.

"If these considerations have been sufficient to show the expediency of further supervision over the railway system, a question will next arise as to the manner in which such supervision should be applied. Those who complain of existing abuses are in general disposed to recommend that the Commissioners of Railways should be intrusted with a direct power of interference for their prevention. Thus, for example, they would propose that the Commissioners should be empowered, in case they should consider it necessary, to regulate the hours appointed for the arrival and departure of the different trains, and to make other arrangements for the working of the line,—to prohibit the use of engines supposed to be attended with danger,—to dismiss the servants of the Company in case of misconduct,—or to require the accounts of the Company to be kept according to some specified form. Without undertaking to say that in no case may direct interference ever be required with regard to matters of this kind, the Commissioners entertain a strong opinion of the impolicy of any such general interference, so long as there is any prospect of attaining the objects in view by other means. The result of frequent interference on the part of any superintending authority with the ordinary management of such an undertaking as a railway, might not only be to engender a feeling of dissatisfaction or hostility on the part of the Company, but to relieve them in a great degree from that responsibility which at present attaches to them, and to create a division of authority which must be any thing but conducive to good management, and to the safety and convenience of the public.

"With these views, the Commissioners abstained from introducing into the Railway Bill of last year any general powers of interference with the ordinary management of railways. They were of opinion, that with regard to future legislation, one of the first duties of the new Board ought to be, to seek for such powers as might enable them to obtain full information with regard to all matters connected with railways, and more especially with reference to any complaints or abuses which might be brought under their notice, with the view of enabling them to form a correct opinion thereupon, and, if necessary, to report to Parliament on the subject. Accordingly, clauses were introduced into the Bill, enabling the Commissioners to call for full information and returns from Railway Companies, and, if necessary, to test the accuracy of such returns by reference to books and other documents, and also imposing on the Commissioners the duty of reporting to Parliament, at stated periods, on various matters connected with the condition and management of railways.

"The Bill so framed had to encounter two classes of objections directly opposed to each other. On its first introduction, the prevailing objection to its provisions appeared to be, that they did not go far enough in the way of interference and regulation, and that they were not sufficiently stringent in providing for the safety and accommodation of the public. Without again adverting to the difficulty of any more direct and general interference with the ordinary management of railways, it may perhaps be shown that the measures proposed under the Bill might prove, in practice, more efficient for the remedy of abuses than they at first sight would appear. It must be recollected, in the first place, that the mere exposure of an abuse is of itself, in many cases, an important step towards its remedy, especially when those with whom the decision rests are themselves amenable to public opinion. But in the present instance, an additional and more efficient check would be found in the power reserved to the Commissioners, of reporting to Parliament upon all matters of this kind. Railway Companies being created under Acts of Parliament, the use or abuse of their powers is a proper subject for Parliamentary inquiry, and it is competent for the Legislature at any time to interfere either by general or by special legislation. But even supposing Parliament to abstain from originating measures for such direct interference, Railway Companies are, in the ordinary course of their affairs, obliged to apply to Parliament, from time to time, for new powers; and an opportunity is then afforded of correcting any abuses which may have been shown to exist, and of marking the sense which Parliament may entertain of any improper proceedings. Under these circumstances, it must reasonably be expected that due attention would be paid to the recommendations of a public Department intrusted by the Legislature with the supervision of our railway system. But if it should afterwards appear that there are particular points upon which a power of more direct regulation is required, it will be easy to supply such defects in our legislation, when they have been proved by experience, without incurring the danger likely to arise from the adoption of a system of general and indiscriminate interference.

"The other class of objections against the Bill were those of the Railway Companies, who complained of its provisions as an improper interference with their private affairs, and as likely to prove injurious to their interests, without any corresponding advantage to the public. If, however, as has been attempted to be shown, the management of a railway must necessarily be liable, to some extent, to the evils of a monopoly; and if those evils are to be in any degree corrected by the control of some superintending authority, it is difficult to understand how that control can be exercised in a less offensive and objectionable manner, as regards the Company, than by the simple power of obtaining information, and making Reports thereon to Parliament.

"In 1840, the Committee of the House of Commons on Railways distinctly recorded their opinion that Railway Companies must practically be monopolies; that such monopolies ought to be subjected to the superintendence and control of some Department of the Executive Government, and that such Department 'should have the power to call for any returns, financial or statistical, which, in the judgment of that Department, may be necessary for the performance of its duties.' In the following year, the Officers of the Railway Department of the Board of Trade, in a Report, signed by Mr. G. R. Porter, Sir Frederic Smith, and Mr. S. Laing, expressed their concurrence with the views of the Committee, and their opinion that 'it is indispensable that the Department intrusted with the supervision of railways should have the means of obtaining full information on all points connected with the working of the railway system.' If these powers were considered indispensable at a time when the railway system was comparatively in its infancy, it can scarcely be contended that they should now be withheld, when that system has become so extensive and complicated, when the financial transactions of Railway Companies are conducted on so gigantic a scale as to be supposed to exercise an important influence on the general finances of the country, and when the supervision of railways has been considered by the Legislature to be a proper object for the establishment of a distinct Department of the Government.

"It is not easy to understand what legitimate grounds of objection can be taken to the power of inquiry which has been proposed. For what good purpose can secrecy be required in the ordinary financial transactions of such a public body as a Railway Company? If these transactions have been conducted in accordance with the law, and with a due regard to the interests of the shareholders and of the public, the character of the Directors and of the Company will only gain by the most complete publicity. If, on the other hand, illegal transactions have been permitted,—if the funds of the Company have been appropriated to purposes to which they were not by law applicable, or their accounts have been kept in such a manner as to create an erroneous impression as to the real financial state of the Company, it will be equally the duty of the Legislature to take measures for enforcing the law, and the interest of the shareholders to prevent such illegitimate transactions.

"An opinion has of late gained ground that, with the view of preventing such proceedings, it may be conducive to the interests, as well of shareholders as of the public, that some means should be provided for enforcing an audit of the accounts of Railway Companies, by the agency of some independent authority. The suggestion may be well worthy of the consideration of the Legislature. But the proposal of the Commissioners involved no such extensive proceeding as a general audit of the accounts of Railway Companies. They simply recommended that, in such cases as might appear to call for their interference, they should be invested with the power of examining and of reporting the result to Parliament. It is impossible to deny that numerous cases have occurred in which such a supervision might have been usefully exercised. Even under the present imperfect system of obtaining information, by means of returns under references from Parliament, numerous instances have been discovered of the misapplication of the funds of Railway Companies. In the Financial Reports made by the Commissioners to the House of Commons in the last session of Parliament, many cases will be found in which the capital of Railway Companies has been advanced to other public undertakings without any authority in their Acts. In the case of transactions between different public bodies, it may not be difficult to bring these irregularities to light; but without some additional power of investigation, it must be impossible to obtain information respecting those financial transactions of Railway Companies, which have reference only to their own funds, and in which other public bodies have not been concerned. And yet such transactions are equally liable to abuse, and may be equally or even more important as regards the interests of the shareholders and the public. To take only a single instance,—Suppose that the Directors of a Company, being anxious for some object to keep up the price of shares, and for this purpose to create an erroneous impression as to the prosperity of the Company, should think fit to misappropriate a portion of the capital of the Company in swelling the dividends payable to shareholders. By this means a serious delusion would be practised on the shareholders, and a positive fraud might be perpetrated on those amongst the public, who might be tempted by these erroneous representations to purchase shares at a price not justified by the actual state of the undertaking.

"It is unnecessary to multiply examples of this kind, and it may be sufficient to add that the experience of the Commissioners, since they entered on the duties of their office, has only served to confirm them in their opinion, that such a power as that which they have suggested is both reasonable in itself, and necessary for the due protection of public interests.

"In conclusion, the Commissioners of Railways would recommend that, in any Bill or Bills which may be introduced into Parliament for the further regulation of railways, provision should be made for the following objects:

"1st. For instituting preliminary proceedings with respect to Railway Bills, with the view of securing a more careful consideration of railway projects, particularly with reference to the interests of land-owners, and also for transferring the consideration of engineering questions from Committees of the two Houses of Parliament to a more competent tribunal, with the view of relieving those Committees of a burthensome duty, and at the same time diminishing the existing evils of delay and expense.

"2nd. For amending the present statutes with reference to the *opening of railways*, *bye-laws*, *cheap trains*, and *conterminous railways*, in the manner already suggested in this Report.

"3rd. For enabling the Commissioners of Railways to obtain full information on all matters connected with the working of the railway system, and to report their opinions thereupon to Parliament.

"The Commissioners regret that the completion of this Report has been unavoidably delayed to a later period than was intended, in consequence of the unexpected and lamented death of their late colleague, Colonel Brandreth.

(Signed) "EDWARD STRUTT.
"GRANVILLE.
"EDWARD RYAN.

"*Office of Commissioners of Railways*,
Whitehall, March 31, 1848."

Lieut.-Colonel Brandreth was in the bosom of his family a cheerful companion, an enlightened and an endeared friend; his feelings were regulated by Christianity throughout, and by them he kept his mind pure and his conscience tender, applying the Christian test to every principle. His political opinions sided with those of the reform party, but ran into no exaggerations; he thought that the most essential element of gradual reform was the education of all classes. This slight sketch of his successful services will, it is felt, be read with interest by every Officer of the Corps; and though the loss of these services has now to be deplored, it is hoped that their record will serve as a stimulus to the younger Officers to follow his honourable career, and to promote, like him, the reputation and public character of their profession.

G. G. Lewis,
Colonel, Royal Engineers.

II.—*On the Defence of the Country south of London; a Sequel to the First Article of the 9th volume of Professional Papers. By Colonel* LEWIS, *C.B., Royal Engineers.—With a Plan.*

"Les ressources défensives des nations ne sont pas aujourd'hui une mystère pour personne."

VIEWING the question as before, hypothetically, that an hostile army had landed on the south coast of England, it is now proposed to consider the means to prevent an advance upon London, or to obstruct and delay the movements of the enemy in his progress to the position contemplated in the article of the 9th volume of these Papers, 'for the Protection of the Metropolis.'

That position, having Woolwich for the left and Windsor for the right, a line of defensive works of about 30 miles, is not sufficiently extensive to form a base of operations for the defence of the coast between Portsmouth and the North Foreland: the following will demonstrate the practicability of taking up new positions in advance, although as a project the proposition may be deemed of less importance than the defence of London, and therefore second in consideration.

The subject is therefore given as a sequel to the former; it was not omitted, as might have been supposed, because the scheme was impracticable, but because of less import, as the perusal of these pages will show.

Previous to discussing the defence of the country south of London, and not to weary the reader with observations as to the practicability or impracticability of an invasion, or of the defenceless state of the country in the event of a sudden war, some extracts are given from a French work upon the subject, together with the views of Mr. Pitt with regard to the land defences about sixty years before.

The Opinions of our Neighbours in France as to the Value of our Defensive Means.

However indifferent the people in England may be in regard to their insecurity, and however unwilling to entertain any propositions that incur a vast

PLATE I.

MAP
OF THE
South Coast
OF
ENGLAND
To explain the Articles
OF THE 9TH & 10TH VOLUMES OF
"Professional Papers"
STRAITS OF DOVER
PART OF FRANCE
THAMES
SHEPPEY I.
L. OF THANET
MARGATE
RAMSGATE
SANDWICH
DEAL
DOVER
FOLKESTONE
Hythe
CANTERBURY
Faversham
Sittingbourne
Milton
Sheerness
Whitstable
Herne
Herne Bay
Ash
Chartham
Chilham
Charing
ASHFORD
Wye
HEADCORN
RAILWAY
Tenterden
ROMNEY MARSH
N. Romney
Lydd
Dunge Ness
Rye
Winchelsea
ASTINGS
Southend
Rochford
SALISBURY
SWINDON
Highworth
Lechlade
Marlborough
Ludgershall
Amesbury
Christ Church
The Needles
CALAIS
BOULOGNE
Etaples
MONTREUIL
RIVER SOMME

outlay to prevent danger they cannot see, and who repose on the strength and effectiveness of our wooden walls, the French army is perfectly alive to our insecurity and contempt of danger, as the following extract from a recent work by Lieut.-Colonel Ardent, of the Corps du Génie, will explain.

"En regard de ces prodigalités on ne peut prévoir la limite, mettons la prudente économie[1] de l'Angleterre.

"Cette puissance n'a jamais songer á élever des retrenchements sur ses côtes, excepté en 1805, ou elle a pris au sérieux la menace de Napoléon. Les travaux commencés à cette epoque ont été suspendus aussitôt que le danger a paru s'éloigner. Il n'est resté que les tours Martello, élevées sur la plage qui s'etend de la Tamise au cape Beachey. C'est aussi de cette époque que datent quelques ouvrages de fortification élevées à Douvres et à Corke en Ireland.

"Parmi les ports militaires de la Grande Bretagne, le plus important de tous, celui qui est le point de réunion de la flotte Britannique et le centre de tous les grands armements, Portsmouth est seul fortifié dans toutes ses parties et ses dépendances. Les trois villes de Gosport, Portsmouth, et Portsea, situées la premiere à l'ouest, les deux autres à l'est de l'entrée du port, au fond d'une petite baie protégé par des batteries, sont couverte chacune par une enceinte. Mais ce qui ajoute beaucoup á la force de cette position, c'est que Portsmouth et Portsea sont dans une île retranché; en sorte qu'on peut dire de ce vaste ensemble d'etablissements maritime et militaire qu'il est fortifié avec luxe.[2]

"Chatham est l'arsenal le plus considérable de la marine Anglaise, car c'est là que sont les grands chantiers de construction pour les navires de guerre. Ce port, situé dans la Medway, à huit ou neuf kilomètres de son embouchure, est mieux protégé contre les attaques par mer qu'il ne l'était en 1697, lorsque Ruyter vint y brûler la flotte Anglaise. Cependant la batterie de Sheerness, qui défend l'entrée de la Medway, est très faible et n'arrêterait pas un Amiral résolu. L'arsenal de Chatham n'est couvert, du côté de terre, que sur le bord sud de la Medway; en se portant sur la rive nord après un débarquement, on pourrait facilement brûler, non seulement l'arsenal militaire, mais aussi les villes de Chatham et de Rochester.

"Plymouth est, après Portsmouth, le second grand port militaire; son arsenal, ou *Plymouth Dock*, est fortifié; la ville commerciale n'a point d'enceinte; l'entrée de son port est seule protégé par une citadelle. Il faut reconnoître au surplus, que des débarquements seraient difficiles à effectuer dans les environs de cette ville, et que l'ouverture de la rade est bien défendue par des batteries.

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[1] The object of Lieut.-Colonel Ardent's work is to show that the expenditure of the French Government '*pour le protection de son littoral et de ses ports*' has been too prodigal, at the expense of a part of the frontier of the French empire, and neglecting that department, 'Moselle,' of which this Officer was a representative in the Chamber of Deputies.

[2] Query, should be?

"Douvres est la place maritime à laquelle les Anglais ont le plus travaille en 1805. La ville est située sur une plage, entre deux points fortifiés; le vieux château à l'est et un camp retranché à l'ouest, mais elle n'a elle même aucun rampart du côté de terre.

"À Falmouth, il y a une citadelle qui, conjointement avec une batterie située vis-à-vis d'elle, défend l'entrée de la baie Carrick, mais la ville n'est point fortifié contre un débarquement.

"Aucun grand port marchand n'a de fortification digne d'être cité: à Liverpool, on ne peut donner le nom de fort à une caserne défensive placée à l'extremité de la ville, sur la Mersey, pour observer la rivière.[3]

"Hull ou Kingston, à l'entrée de l'Humber, l'un des quatre grand ports commerçants de l'Angleterre, le premier pour le pêche de la baleine, dont la marine jauge 70,000 tonneaux, n'est nullement fortifié.

"Bristol, sur l'Avon, ne l'est pas, ni Brighton ni Exeter, ni une foule d'autres villes riches ou commerçantes situées sur la côte qui fait face à la France; et pour aller jusqu'à Londres même. * * * * * * * * * *Cette sobriété des Anglais*, en ce qui concerne les fortifications, ne prends pas sa source dans un système de défense active, qui a sur celui de la défense passive un grand avantage, car les dépenses qu'il occasionne ne sont jamais stérile; elles ont des résultats applicables à l'état de paix, en attendant que l'état de guerre réclame l'emploi exclusif des ressources qu'elles ont du créer. * * * Voici en effet la situation respective des deux pays.

"En France la majorité des intérêts est basée sur l'agriculture. Le commerce et l'industrie, quelque respectable qu'ils soient, sont loin de posséder des valus comparables à celles que nous procure chaque année la culture de notre sol.

"En Angleterre, sur seize millions d'habitants il y a douze millions et demi d'industriels. Notre fortune est foncière et immeuble pour ainsi dire, celle de l'Angleterre est essentiellement mobilière.

"Notre commerce maritime, quoique peu important en comparison de celui de l'Angleterre, est réparti dans un nombre considérable de places commerciales, sur tout se développement de la vaste entendue de nos côtes.

"Presques toute la richesse commerciale et industrielle de la Grande Bretagne est concentrée dans la sud de l'Angleterre, sur un territoire peu entendu. Les navires, mouillés dans le seul port de Londres, ont un tonnage qui dépasse de un quart celui de toute notre marine marchande.

"Nos côtes sont hérissées de fortresses, les ports marchands Anglais sont absolument sans défense. Nous avons chez nous une belle et grande institution qui appelle tous les citoyens à la défense du pays. En Angleterre il n'y a que des milices, qui, par leur organisation encore féodale, par leur armement, par leur discipline et par leur nombre,

[3] This observation is no longer correct.

ne peuvent soutenir la comparison avec notre garde nationale. * * * Mais si soixante mille Français prenaient terre entre Hastings et Douvres et qu'une bataille heureuse leur permit de s'avancer jusque sur les bords de la Medway et de la Tamise, ils pourraient, en vingt-quatre heures, détruire plusieurs milliards de matériels et de marchandise, et porter à la fortune de l'Angleterre un coup dont elle aurait peine à se relever."

These truths, if inculcated at home, it would be deemed impolitic to promulgate, and inexpedient to publish; but coming from our neighbours, the facts cannot be disguised, and the Legislature should not shrink from an investigation, and the consideration of remedying such dangers as may exist.

A Sketch of certain Propositions for extending the Fortifications, submitted to the House of Commons in the Session of 1786, *as published in the Annual Register of that year.*

"On this occasion Mr. Pitt observed, that it had been his original intention to have suffered the matter of the fortifications to have been decided by a sort of indirect vote in the Committee of Supply; but from the extraordinary degree of censure and animadversion it had experienced, and from the determined opposition which it seemed to be the intention of many to exert, he was induced to wish that a different method of arguing the question should be adopted, and that the matter should be brought forward in the most specific and solemn manner. * * * *

"To prove the utility of the fortifications, Mr. Pitt appealed to the unfortunate and calamitous situation in which we were placed in the late war. A considerable part of our fleet was confined to our ports, in order to protect our dockyards; and thus we were obliged to do what Great Britain had never done before, to carry on a defensive war,—a war in which we were under the necessity of wasting our resources, and impairing our strength, without any prospect of any possible benefit by which to mitigate our distress. Mr. Pitt felt the question to be a portion of that momentous system which challenged from its nature the vigilance and support of every Administration. Shame and affliction were brought upon us by the American war. Was the House ready to stand responsible to posterity for a repetition of similar misfortunes and disgrace? Were they willing to take upon themselves the hazard of transmitting the dangers and calamities which they themselves so bitterly experienced? * *

"Mr. Pitt was very assiduous in removing the objections that had been advanced in order to diminish the credit of the Report. He observed, that it had been imputed to the Administration, that the instructions given to the Board of Officers were such as confined them to the necessity of coming to one certain result, by means of data proposed to their consideration, which were merely hypothetical, and afforded no latitude to them for the exercise of their judgment. But how was it possible this should be the case when the two first data, if granted, decided upon the necessity of establishing fortifications, and when the whole Board were unanimous in admitting them? Was it credible that such men could have been duped by chimerical hypotheses, so absurd and extravagant as to be tantamount to a convulsion of nature? The principal data upon which several parts of the Report proceeded, were also not the original data referred to the Board; but such as they thought necessary to introduce, and substitute, as a foundation for their ultimate opinions. * * *

"It had been one objection with the enemies of the system, that the idea of fortification was new and unprecedented in this country. But this assertion Mr. Pitt was prepared to combat in the most direct and positive manner. He appealed to the statutes of King Henry the Eighth for the truth of his observation. The same policy was observed by Elizabeth, and formed a considerable part of the defence provided by that great princess against the expected attack of the armada. During the reign of the House of Stuart, the same system was occasionally continued. Under Queen Anne, when the victories of the British armies were forming the admiration of Europe, our ancestors did not think it incompatible with their fame or their liberties to apply a considerable sum to the fortifying the most valuable part of their coasts. * * * * * * * *

"Mr. Pitt observed, that there was a consideration which ought to have more weight than others, and this was, that the fortifications, being calculated to afford complete security to the dockyards, would enable our fleet to go on remote services, and carry on the operations of war at a distance, without exposing the materials and seeds of future navies to destruction by the invasion of an enemy. It had been insinuated that the second datum in the instructions had proceeded upon the supposition of the fleets being absent for an improbable time. The fleet had been absent in the last war for a time, nearly equal to that which was supposed, upon a service with which this country could not have dispensed without sacrificing the most brilliant success of the war. Had we then been in fear of an attack upon our coasts, which from reasons, not proper to be mentioned, we happened not to be,—Gibraltar,—the renown of defending it must have been for ever lost. But it was not only by foreign expeditions that we might lose the aid of our fleet in case of invasion; it might so happen that the ships, though in the very Channel, might be prevented by contrary winds, tides, and other contingencies, from arriving to the assistance and relief of the dockyards. Upon the whole, Mr. Pitt thought the present question was rather to be considered as connected with our naval establishments than with those either of the army or the ordnance. Were it to be asked, why the sum to be required for these fortifications had not been demanded for strengthening the navy, he would fairly answer, that the money which would prove sufficient to accomplish these works would not build so many ships as would serve for the defence of our most valuable harbours. There was, besides, a certain degree beyond which the navy of this country could not go. There was a certain number of ships, beyond which we could neither build nor man any more. The true limit he could not, nor would it be prudent for him to assign; yet, in the nature of things, such a limit must exist. But there could never be any line drawn to restrain the security which we ought to provide for our dockyards. * * * * * * * *

"Mr. Pitt called upon the House to beware how they suffered themselves lightly to be drawn into a line of conduct which might involve their posterity in accumulated evils; and he suggested to their recollection the remorse which they must feel, if they should hereafter find that they had, by an ill-timed pertinacity upon the present occasion, brought upon their country calamity and ruin."

It is needless to remark that these propositions were rejected by a majority of one.

THE CONSIDERATION OF PROTECTING THE COUNTRY SOUTH OF LONDON.

In considering the means of protecting the country south of London by means of fortifications, should a successful debarkation be made on the coast between Selsea Hill and the North Foreland, the state of the existing defences, or their improvement, will not be adverted to; but a system of defence will be proposed in addition to them.

Until the introduction of steam navigation, the only vulnerable part of the south coast was considered to be that between Beachey Head and the River Thames, and the intermediate country to be defended was the banks of the Medway.

Now the most vulnerable part of the coast is between Selsea Hill and Beachey Head, which brings the capital of the empire within 60 miles, and the country between is more open and accessible than the wealds of Kent and Sussex.

The value of fortresses in the defence of empires was discussed in the ninth volume, and their nature and application explained. Here the principles laid down in that volume are proposed to be adopted for the country south of London, with a view to the importance of permanent works being constructed to meet and avert the danger whenever it may arrive: it is also considered as a military question, should the public ever consent to the necessary expenditure.

The system of defence proposed embraces the occupation of two lines concentric with the coast.

The first line is conceived to have Chatham for its left, and Portsmouth, which should be considered the bulwark of the empire, for the right; the former occupied by 15,000 men, and the latter by 20,000 men, and to place three strategetical[4] fortresses between them. This line extends 80 miles, and consequently the openings between these fortified places would be something less than 20, (*vide* Plan,) and between which it is imagined no enemy could pass and leave them behind.

The second line, and in advance, is imagined as extending from Canterbury on the right, to Chichester on the left, forming a line of field fortresses (places du moment),[5] or rather a range of fortified barracks, placed sufficiently near to the coast, by the assistance of the existing railroads, to enable the troops to dispute the debarkation of an enemy. In selecting the sites for the strategetical fortresses between Chatham and Portsmouth, we should be guided by the nature of the country, and the line of common roads and railways. Working from the left, the defence of the Medway and weald of Kent seems to point out the ground between Tunbridge and Tunbridge Wells for the first strategetical fortress. The next point to be occupied should be near Cuckfield, which commands the approaches to London from Brighton; and the third fortress near Pulborough, at the junction of the roads leading to London from Chichester and Arundel.

Without going into engineering details, these fortresses should be made sufficiently large to hold 6000 men as garrisons, of which one-half or two-thirds might be composed of a local force embodied especially for their defence; and by taking advantage of the ground, to render unnecessary the execution of expensive fortifications; but so constructed as to oblige an enemy to bring heavy artillery for their reduction, and a siege operation of a month after the investment.

The line in advance of the above would be merely military posts, contiguous to considerable towns, which together would form a place du moment of some importance, and, in the absence of the regular forces, could be defended by a local force.

The points proposed to be taken up by fortified barracks are Canterbury, Ashford, Battle, Lewes, Shoreham, and Chichester, which are well suited, by their connection with railroads, for the transport of troops laterally and to the coast in front. Accommodation for about 2000 men should be constructed at each of these places upon the principle before explained, combining a force $\frac{1}{10}$th cavalry, $\frac{2}{10}$ths artillery, and $\frac{7}{10}$ths infantry.

[4] See Section 4, Article I. of the ninth volume.

[5] Ibid. Section 6.

With a proper supply of railway carriages always at each post, and a well-combined arrangement with the railway establishments, this force could be conveyed in half an hour to any point threatened; and perhaps the forces of two or more of these military posts might be united on one spot, which would effectually prevent an enemy landing, or if landed, drive him into the sea; for there is not a more difficult operation in war than that of effecting a debarkation in face of large forces.

The works of defence on the coast, on which it is not intended to suggest any remarks, need not be numerous, or very strong or expensive, supported, as here suggested, by moveable columns. What are principally required on an open shore are a few pieces of ordnance, to prevent debarkation in small numbers, or predatory landings, and to secure the entrances of the small harbours; for coast defences, unsupported by troops, are unavailing against a determined enemy, but if of sufficient strength to hold an hour or two, would fulfil all that is required as regards the line of shore between Portsmouth and the River Thames.

FORMATION OF AN ARMY AS AN AUXILIARY FORCE TO THE INFANTRY OF THE LINE.

The regular force in the country in time of peace rarely exceeds 60,000, the major part of which may be considered to be required in aid of the civil power, and not above one-third of that force would be available to meet an enemy, south of London, on the breaking out of a war.

If, therefore, 75,000 men be necessary at such a period, exclusive of irregular troops, the question to be considered is, how can we resist successfully an attack upon our shores, as well as domestic danger suddenly brought to bear upon every part of the kingdom, and provide men for the system of fortifications suggested here, and in the former volume?

An army must therefore be raised as an auxiliary force to the infantry of the line, suited to a state of peace, adapted exclusively to the security of the country, and embodied in anticipation of danger.

The enrolment of the militia, if only carried into effect at the commencement of a war, would be too late; they could not, under such circumstances, be sufficiently disciplined to enable them to take the field against an enemy: this force is also very unpopular, as it presses unequally upon the people, and in time of peace is too expensive.

The yeomanry of Great Britain, by their manly pursuits and habits, are qualified to form the constitutional force of the country; and if infantry, armed with the rifle as *irregular troops*, were added to the yeomanry in the rural districts bordering on the coasts, the two services might act admirably together: every encouragement should be given to the organization and equipment of such a force. It may be asked, if we have no militia, what security there is, in the event of the regular forces being engaged in our Indian, Colonial, and petty wars, by which the country may be frequently denuded of troops?

To meet such a contingency, it is suggested that an army should be raised in anticipation of the working of the warrant of 1847, which limited the enlistment of the soldiers to 10 and 12 years, and which warrant apparently contemplated the formation of an army of reserve at the expirations of those terms; but as either of those periods is too remote, it is proposed to organize at once 100 battalions of six companies each, and of men between 25 and 35 years, for home service. These ages would not interfere with the recruiting of the line; and as their enlistment should be likewise for 10 years, the men from the line would keep up the strength of the reserve battalions, as they might be called.

In order to render this force perfectly effective, it is likewise proposed to give one of these battalions to each regiment of the line, and to officer it by its present establishment, making it, as it were, the dépôt battalion, and attaching the recruits to it, so as to become a school of instruction, and the head-quarters of the regiment.

To render this plan economical as well as effective, and to amalgamate perfectly the reserve and active battalions together, there should be only one permanent mess and one band at head-quarters, and detachment messes similar to those of the dépôt companies for the active battalions.

Whether the regiments of the line should have, as at present, one or two battalions, is a question foreign to the proposed scheme, except that one reserve battalion will be sufficient as a dépôt and head-quarters for the whole regiment, with one set of Officers, each Officer taking his turn for foreign service, whether the regiment has two or three battalions. It might be deemed advantageous to place the head-quarters under the command of a full Colonel, making that rank a regimental one, similar to the Marines and Ordnance Corps; and when the active or service battalions are at home, to brigade them and the reserve battalions together. Many other advantages would accrue by this arrangement; among others, that of giving a sort of permanency to the command, and insuring an efficient Officer in charge.

The expense of 100 reserve battalions attached to the regiments of the line,[6] compared with the same number of battalions of militia, would be very moderate, probably not one-third; and this augmentation would raise at once an effective force.

SUGGESTIONS AS TO THE MODE OF PROVIDING FUNDS FOR THE NEW FORTRESSES AND BARRACKS.

It is improbable that the country will ever consent to the construction of expensive fortifications and barracks out of the revenue; but as circumstances may occur to induce the public to admit the necessity of a vast outlay as the least infliction upon themselves and posterity, the means of providing funds to carry out the proposed system of defence are here given.

It has been calculated, in the preceding volume, that the immediate defence of London would cost three millions of money.

The three fortresses here proposed would cost one million.

The barracks for 30,000 men, one million and a half.

It is also conceived that it would require one million and a half to complete the existing fortifications, to construct new batteries along the littorals of the United Kingdom, and to supply the works with artillery and stores.

This amounts to seven millions, to be acquired by loans, which must necessarily be added to the amount of the national debt; but as it would occupy three years to carry the various projects into effect, these loans might be spread over that period.

By no other means could the necessary funds be raised: if voted annually, they would probably be applied to other services deemed more pressing; or, in the event of the revenue falling short, the vote might be postponed; and assuredly, as soon as the emergency and alarm subsided, the money would be withheld.

If the Legislature, supported by public opinion, provided for these funds,

6 The augmentation of the Royal Artillery has been taken up by Major-General Sir Robert Gardiner, a distinguished Officer of that corps under the Duke of Wellington in the Peninsula and in France, in an able Report to the Committee of the House of Commons. The augmentation of the Cavalry would be easily attained by simply increasing the rank and file.

a Commission might be appointed for the due appropriation of the money, under trust, and the completion of the works secured.

CONCLUSION.

This proposition for the defence of the country south of London, given as a sequel to a former Paper, has been discussed and treated as a question purely hypothetical, and is now submitted as a problem for the purpose of demonstrating the elements of resistance,—admitting, first, that an enemy could land a large force between the Thames and Portsmouth; secondly, if landed, that there is no impediment or difficulty between the coast and London; thirdly, that there are no existing defences, natural or artificial, of a passive kind, and the active are few and far between, and, if collected, would be insufficient; and lastly, as a conclusion not to be controverted, that the military resources, such as they are, are not intended for the defence of the empire, and consist only of such establishments as are necessary for the supply of our fleets, colonies, and military dépôts, destined for foreign service.

Colonel Ardent, of the French Engineers, has given a description of our arsenals and fortifications sufficiently correct to instruct this country, as well as France, if we are willing to learn; and the extracts from the speech of Mr. Pitt forcibly point out the course to be pursued, if we are convinced of our danger: but nothing is so difficult as to bring disagreeable truths home to the mind; and when indolence, ignorance, and sordid feelings prevail, there is nothing left but to wait events, and the chances of escape when danger arrives. Hence the defence of the coast, the country, and London itself, has been treated hypothetically for the instruction or amusement of those who take an interest in these matters.

The first point to consider, as a military question, when a line of coast is threatened with danger, and an enemy would probably attempt to debark in force, is the means of throwing a powerful column of two or three thousand men on the sea-shore to oppose such landing from points fixed at certain distances in rear, parallel with the shore; or, in case of a partial landing, to drive them into the sea; or, if the landing were perfected, to hold them in check until reinforcements could arrive.

To accomplish this, *steam* must be opposed to *steam;* and for this purpose it has been proposed to establish several strong military posts between Canterbury and Chichester, both inclusive, parallel with the coast, with the means of transport by rail, when the alarm is given, to move down a force of infantry, cavalry, and artillery combined. But the difficulty is to guard a shore 100 miles in extent; and fogs, or accidents, might favour an enterprising enemy.

Secondly, as an engineer question, under the latter possibility, that a debarkation is effected and secured, the defence of the country between the coast and the metropolis has been provided for by the emplacement of three considerable forces and by the occupation of the barracks and the environs with local forces; and gradually, under their protection, to augment and support the force in the field which has been endeavouring to check the enemy's advance. These posts, particularly the fortresses supplying the troops with ammunition, stores, and provisions, are important considerations; for it must not be supposed that the men will have time to go in search of either. And another essential advantage, easily understood by military men, but little thought of by non-combatants to whom this Paper is addressed, is that of the troops having been previously brigaded together, capable of moving in masses between the fortresses and fortified barracks already alluded to. It should be explained, that in the event of the coast being threatened with an invasion, regiments and corps of infantry, cavalry, and artillery, cannot be brought from all parts of the country, hurry scurry, upon the enemy. A certain organization of these forces into brigades and divisions is necessary, previously arranged, with an intelligent Staff, or the troops will be beaten in detail, and the whole country thrown into confusion and dismay; but, supported by the military posts, the movements of the several columns, whether in advance or retreat, would be regulated without confusion or difficulty.

Thirdly, as war is an uncertain game, and as an enemy might be able to advance in spite of the fortified positions, the third line of defence is ready to receive him, as proposed in the ninth volume. On this line the whole strength of the nation would be collected to preserve the metropolis. Here, with the works in front and in flank, a successful defence might be calculated upon.—*Vide* Plan.

Such is the substance of the two Papers on the Security of London and the Country South, comprising a system of passive defence in aid and support of our active forces;—a combination of means not easily overcome,—a system which, if carried into effect, would certainly deter an enemy from attempting an invasion on our southern shores.

By the adoption of the other and more popular course, *laissez faire*, 'sufficient for the day is the evil thereof,' concurring with the inclination to attack absorbing the minds of a rival and jealous people, with opportunity and many chances of success, all combining against what Colonel Ardent terms the *sobriété des Anglais*, it is difficult to calculate upon the possible losses, if that *sobriété* should be found to be a mistake.

Portsmouth, 6th July, 1848.

III.—*Report on the 'Great Britain' Steamer,*[1] *ordered by the House of Commons to be printed,* 16*th July,* 1847.

Dundrum, Ireland, 2nd July, 1847.

SIR,

Having on the 23rd ultimo received your instructions to proceed to Dundrum, in pursuance of directions from the Lords Commissioners of the Admiralty, and to report upon the present state of the *Great Britain*, the nature of the works by which she has been protected, and the prospect of getting her off; also, whether any temporary assistance can be afforded by the Admiralty Department at the time of making the attempt,—

I have now the honour to report, that I arrived at Dundrum on Sunday evening, the 27th ultimo, a high spring-tide falling on the day following, which was likely to have an important bearing on my inquiries.

Next morning I put myself in communication with Captain Claxton, who is in the immediate superintendence of the operations for the recovery of the *Great Britain.* The most cordial co-operation was at once tendered me by this Officer, which secured to me, from every person concerned, the most ready, unreserved, and obliging assistance and access.

The spot on which the vessel lies is upwards of three miles from Dundrum, in a direct line across the sands, which are passable at low water, and about five and a half round at high water, when they are impassable. Her bed is apparently a soft sand; but the rocks, which lie at an average depth of about four feet, approach nearer to, and even protrude through, the surface here and there; and on one or more of these the vessel has evidently been working.

The general state, however, of the ship corresponds with the newspaper accounts; her lines and general form are as true and symmetrical as when she was launched, evincing that her frame has suffered no strain. The exact extent of the injury to her bottom cannot be ascertained till she is farther

[1] By permission of the Lords of the Admiralty.

lifted out of the trench she has worked herself into. A hole on the starboard side, large enough for a man to enter, was sufficiently near the surface of the beach to be got at and repaired. The principal injury is under, or forward of, her boilers, which have been forced up about fifteen inches, lifting the deck immediately over them, and causing the only perceptible disturbance in her upper works. A bruise is also apparent under her counter, and her rudder-post and rudder are carried away, the latter lying where it parted, about sixty yards outside her. Her propeller is slightly, and her machinery considerably, damaged.

But there can be little doubt that she has sustained no injury in her hull that cannot be easily got at and repaired, as soon as she can be lifted out of the trough she occupies.

When the works commenced, she was imbedded in sand and rock about six feet; but by the exertions perseveringly pursued by the boiler-makers in repairing and tightening, she is now but 3′ 8″ down at the head, and 2′ 4″ at the stern, with a list to port of about 2′ 0″.

She lies about 150 yards above low-water mark of spring-tides, and on the low-water mark of neap-tides, rather across the beach. Her head N. W. by W.; the Cow and Calf rocks, which appear at half ebb, bearing S. by W. one mile; Tyrella Coast-Guard watch-house N. E. 527 yards; and St. John's light-house S. E. by E. ½ E. about 4 miles. By a sounding which I took on both sides of her at midships, at high-water spring-tide on the 28th ultimo, she had full 12 feet water about her. The beach is excessively flat, with a fall only of about 1 in 100.

All abaft the after end of the engine-room has been made perfectly water-tight; but valves have been left, by which the water is permitted to enter, in order to keep her steady, or is shut out when required.

Every advance in the operation of tightening has been followed by a lift the succeeding spring-tide; and the advantage has been sustained by an ingenious mode of packing stones under her as she rose. Small piles of these were put on trays formed of iron plates, or whatever suitable was at hand, placed at low water as close as possible to her bottom; two ropes were attached to the tail of each tray, and led up to the deck, by which, as soon as a lift of the ship took place, the trays were tilted up, and the stones shot into the cavity. The sharpness, however, of the part imbedded, increasing as she rises, leaves an orifice more and more unfavourable for such an application.

The ship undoubtedly owes her preservation to the breakwater that was constructed around the most exposed part of her stern, but which is now in course of removal for the sake of the poles, which are otherwise required. But for it, she must unquestionably have been broken into fragments by the great violence of the winter gales, the bay being completely open from S. E. to S. W. Captain Claxton was kind enough to procure for me, from one of the Civil Engineers employed, a drawing of this work, which is herewith forwarded in illustration of its construction and application. It was originally intended to consist solely of fagots, or fascines of brush-wood, about 11 feet long and 20 inches diameter, piled at a regular slope against the vessel, from the beach to her upper deck, embracing her from the extreme point of the starboard quarter round to about 100 feet forward of the taffrail on the port side. Every attempt was made to secure them by iron vertical rods driven through them into the beach, and by weights of every description, stones, sand-bags, iron bars, and chains. The heaviest articles, such as the driving chain of the propeller shaft, the damaged cover of the air-pump, &c., were applied as dead weights to the successive tiers. The violence of the seas, however, defeated every expedient, and the attempt probably would have failed but for the intelligent suggestion of enclosing the whole by an outer protection or cradle of green beech poles, planted all round at an angle of about 45 degrees, with others placed across and diagonally, as necessity from time to time dictated. At the most exposed parts they were planted in a triple row, going off to a double one at the less, and a single one at the least, exposed parts. They were from 45 to 52 feet long, 11 to 14 inches thick at the butt, and 5 to 6 inches at the top, and were obtained from an adjoining estate, at a cost of twelve shillings each. Chains embraced them all round, and the foot of every third was secured by other chains to the propeller shaft, or to guns used as anchors. The tops abutted against and rose above the vessel, and were secured on deck by tackles; but it was found necessary to set them free. Even this barrier was sometimes disturbed bodily by the heavy seas; but it was closely watched, and its slope and elasticity yielding to them and breaking their force, enabled it to withstand them sufficiently to save the ship, the greenness and weight of the wood having the most favourable influence on its stability. Eighty poles and 5800 fascines were used, the latter one shilling each.

The successful adoption of this simple expedient could not be too generally known. Cases most frequently arise in which its application would be readily practicable, and many ships, with valuable cargoes, be rescued from destruction. The principal points to be attended to are, to use green and heavy kinds of wood; to place the poles at a proper inclination, and to secure their butts firmly; and it is probable that in most cases sufficient protection would be obtained without the interior fascine-work.

It would evidently be unwise to attempt to take the *Great Britain* to sea without previously repairing her defects in a temporary manner; and means are in active progress for lifting her, so far as to admit an examination of her bottom forward of midships, to which they are now confined, and which cannot be made from within until the sand and water can be got out. A lift of about five feet forward would be sufficient, and when accomplished, a very few days would probably suffice to make such temporary repairs as would carry her to Liverpool or Bristol, where alone there are docks large enough to admit her.

The dead weight to be lifted, after lightening her of every unnecessary burden, is from 1500 to 1600 tons.

Many mechanical appliances are in preparation, the principal of which consists of twenty wooden boxes containing sand, suspended from the heads of forty of the largest baulks of timber, ranged vertically along the ship's sides, and resting on the rock, two baulks to each box.

To attach each box to the mass to be lifted by this counterweight, two blocks or toggles are placed across the inner side of two ports of the dinner saloon deck, to which are secured, by chains passed through the ports, two iron sheaves, each fitted into two pairs of the bars composing the links of the driving chain, and thus forming a block and pulley. An inch-iron chain, one end of which is fastened near the top of the baulk, is passed through each block, and led upwards, over a 14-inch iron sheave, fitted into the head of the baulk, to the sand-box, round which latter it is made fast: thus every box is suspended by two chains from the heads of two baulks, and can rise and fall by means of the sheaves and blocks. After deducting for friction, which in so rough an application will be considerable, the available lifting power will be about 600 tons.

The forms of the boxes vary, so as to conform to the shape of the ship's sides, to which they are to be attached as camels, in the subsequent operation of floating her off.

For further lifting power, a system of levers, to be applied to each side of the vessel, is under construction. A long trestle, 6 feet high, to form the fulcrum, is built opposite each bilge keel, at about 7 feet parallel distance. The beech poles are the levers, forty on each side, connected so as to form a stage on which to place the weights. At my request an experiment was tried, by which it was found that with a leverage of 26 feet, a power of nearly 3 tons may be obtained from each pole, but which in practice may be taken at $2\frac{1}{2}$ tons. From this source a lifting force of 200 tons will be obtained.

Three additional levers of large American elm baulk, 16 inches square, are to be applied at the stem, which, with a load of 8 tons each, and a 46-feet leverage, will produce a lifting power of 120 tons.[2]

In addition, Mr. Bremner and Son, the executive Engineers, intend to employ ten screws of 50 tons power each, to be worked from stages reaching above high water: these will give a lifting force of 500 tons.

If these are insufficient, buoyant applications which are at hand must be resorted to; but the boiler-makers' operations are daily lightening the vessel, and may render such unnecessary.

The boilers, stoke-holes, coal bunkers, and the two cargo decks, have been made water-tight, and firmly secured.

These may be considered as the most important part of the operations; and, if successful, it is not at all improbable that with the concurrence of a high spring-tide, and an on-shore wind,[3] the vessel might be floated off without any extraneous buoyant applications.

A 12-feet tide may be depended on; and according to information received by Captain Claxton from Mr. Patterson, who built her, 14 feet is her light draught line, machinery on board.

The difference between her 14-feet and 12-feet displacements is 507 tons; flotation, therefore, to that extent has to be provided.

The displacement of the twenty sand-boxes, which are to be slightly enlarged when used as camels, is equal to 432 tons. The proposed mode of attaching them seems practicable, and each will be provided with a pump.

A vessel of 80 tons, coming from Scotland with stores, is also to be applied under her stern; and, if necessary, two large barges, of 40 tons each, will be

[2] *Vide* Note at the end of the Report.

[3] An on-shore wind has a tendency to raise the water in the bay.

put in requisition. No difficulty exists in finding further contributions, if necessary, over and above the 592 tons already enumerated.

All the means, therefore, at hand, with indefatigable and able executives, there seems to be a fair prospect of success.

In all operations of this nature, however, fair weather forms a material element of calculation. Any thing like a gale, with a spring-tide, might prove a formidable obstacle and serious delay; and such uncertainty renders it difficult to pronounce when she may be got off. Some little risk has, I think, been incurred by the total removal of the breakwater, although gales are not to be *expected* this time of year. But anticipating propitious weather, the high tides at the end of this month may be considered the earliest time at which she may be floated off; and considering the very few good working days to be obtained, and that some interruptions must be expected, surprise could not be felt if the attempt were delayed till the end of August, at which time, however, the springs would be more than usually favourable.

The aid of two powerful Government steamers to tow her to Liverpool, and of a smaller one to assist the steering, would be invaluable, accompanied with permission to assist at the critical moment of floating her off. Nothing could seem more likely to be conducive to success, at a moment when so much depends on the promptest execution of orders, and the combined exertion of a large body, than the co-operation of powerful vessels, and disciplined and efficient seamen.

It has been suggested that Carlingford Lough would be a safe place of rendezvous. The directors of the operations here might be instructed to communicate, to the Admiral commanding, the period by which every thing would be ready, and the vessels could be summoned by signal from their anchorage at Carlingford, and be at the scene of operations in three hours. No intermediate assistance seems to be needed.

I have the honour to be, Sir,

Your most obedient humble servant,

MONTG^{Y}. WILLIAMS,

Captain, Royal Engineers.

Captain G. T. Falcon, R. N.,

Superintendent of Pembroke Dockyard.

N.B.—On estimating the strength of the American elm baulks, I find that under the given circumstances of position of fulcrum it would not be proper to place so large a weight on each as 8 tons.

In all probability, however, the operations might admit of the fulcrum being brought so near to the ship, that a power little short of my calculation could be produced by the application of a weight the beam would be capable of bearing.

Further Particulars in Elucidation of the Operations by which the 'Great Britain' was recovered from her stranded Position in Dundrum Bay.

On the 30th August, 1847, Captain Claxton, who had directed all the operations, announced to the Secretary of the Admiralty that the ship was finally released on the 27th instant from the unfortunate position in which she had been lying from the previous September, and had safely arrived at Liverpool.

Shortly after, the public, who had watched with great interest the eventful career of this stupendous vessel, was put in possession of the details of the operations connected with her protection through the winter, and ultimate release, by the publication of a small pamphlet, entitled 'Extracts from the Letters of Captain Claxton, R.N., to J. K. Brunel, Esq., and the Directors of the Great Western Steam Ship Company; with a Report from the Chairman to the Shareholders, and Copies of Documents moved for and laid before Parliament.'[4]

These extracts constitute a highly interesting and authentic journal of the principal difficulties, hopes, misgivings, failures, and successes attending the undertaking, written on the spot as they arose. And as they also describe some important contrivances put in practice subsequently to my official visit to Dundrum, and therefore not introduced in my Report, and contain valuable practical information as to how far they and all the other expedients fulfilled, or fell short of, their calculated effects, it is believed that selections from them may be advantageously introduced here, prefaced by a brief notice of the dimensions and construction (taken from 'The Great Britain Atlantic Steam Ship,' published by Mr. Weale,[5] with 25 folios of engravings) of this remarkable vessel.

Length of ship	322 feet.
Beam	51 ,,
Depth	$32\frac{1}{2}$,,

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4 Printed by John Taylor, at the 'Mirror' Office, Bristol.

5 The length and breadth are respectively 76 feet and $8\frac{1}{2}$ feet greater than those of the *Terrible*, the largest war steamer yet built. The length of a first-rate line-of-battle ship is 205 feet.

Draught of water, when fully laden . . .	18 feet.
Tonnage	3500 tons.
Power	1000 to 2000 horses.

Plates of keel, nearly 1 inch thick.

Do. of bottom, varying to $\frac{3}{4}$ inch at extremes, and to $\frac{5}{8}$ inch generally.

Top sides $\frac{1}{2}$ inch, and at the extreme aft $\frac{7}{16}$ inch.

Distance of ribs from centre to centre, amidships 14 inches, increasing to 21 inches at the ends.

Ten iron sleepers run from the engine-room, gradually diminishing in number to the fore end of the ship and under the boilers, the platform of which they support. In midships they are 3 feet 3 inches in depth, supported by angle irons in the form of inverted arches, and a short distance from each other.

She is divided into five water-tight partitions.

Stows 1200 tons of coals.

1000 tons of measurement.

Engines weigh 240 tons.

Boilers weigh 200 tons, holding 200 tons of water.

Number of masts 5 (originally 6).

Propelled by a screw having 4 blades, 15 feet 6 inches diameter, weighing 4 tons.

Screw-shaft, 130 feet long; weighing altogether 38 tons.

The main drum is 18 feet diameter, driving 4 chains weighing 7 tons.

The screw-shaft drum is 6 feet diameter.

Under the whole space of the engines, up to the top, the angle irons are doubled.

The upper main and saloon decks are of wood, the two cargo decks are of iron.

The 'Extracts from Captain Claxton's Letters' commence on the 3rd March, 1847, at which period no specific plan for the release of the ship had been matured. On the 17th he writes—"The mate in charge last night represents to me that the sea at high water rolled along the low side of her deck full as high as the Captain's stage, 10 feet; the tide was a foot and a half higher; and I have no doubt it was so. To-day, as far as I could judge, it was not above 4 feet, or 5 feet above the gunwale; quite high enough to be pleasant, and the feeling and sight fine to a degree. The spars on the breakwater bounded in and out as struck and relieved, or struck by the recoiling sea, from off the fagots, full 5 feet: the sight must have been grand from the shore, but not so fine as yesterday, when I saw at times only three parts of the ship, the intervals being of water about 70 feet to 20 feet of the ship, and each sea, after striking the breakwater and bounding back, meeting another, and dashing first over the aftermast, then over the funnel, and last the foremast."

He went on board at low water after the gale, to ascertain where the ship hung, and describes her as seeming "to work from a bearing under the boilers and engines, and to rise and fall forwards full $3\frac{1}{2}$ feet, and aft a few inches, between the last quarter of flood and the first of ebb, when she must have been beating the rocks under her in a fearful manner."

At this time she was about 9 feet by the head in the dock she had worked herself into; and the extent to which she pummelled away the rock was afterwards evidenced by a shoal of broken fragments, extending from the head along the sands due north, full 200 yards.

By the beginning of May the ship had been partially raised by lightening her of superfluous weight, and by tightening and stopping such defects as could be got at while she lay so deeply imbedded in the beach. These efforts were directed and applied with consummate skill and energy, and often with such success as to excite hopes that she might be sufficiently lifted without mechanical aid; but the springs were falling off, and much remained to be done.

On the 3rd of May, Capt. Claxton writes,—"Our tide effort just over; water at a stand still; ship rose 5 inches, making nearly 2 feet since the first experiment."

And on the 4th,—"I think I shall fill the lower hold with water casks, say 100 puncheons; seeing how the season is advancing, and how hard it is to get at the platform, how difficult to lighten the ship, our friendly vessel having got into a scrape, and no other liking to come. I hate water casks; they are never to be depended upon, but what can one do? I have little hopes of a good tide with this fine weather, and we want 15 feet to do much while so full of water and sand. The port bunker leaked much with the pressure; we must try and tighten it, and get another pump or two in; that and screw alley is all we can do until we can get fairly at the large hole, which, I regret to say, broke out again, and let the water in almost as fast as it rose."

May 5th, he writes to the office,—"I am sorry to write as I feel,—gloomily, almost despondingly. It is over for these springs. I am glad I urged so strongly Mr. Bremner's being sent for: if Mr. Brunel had authorized me to go to work on any plan of his own or my own, it might have been different; but seeing how time slips away, and how low the springs are likely to be until the end of July and August, it is time we prepared some other means for raising her; and certainly Mr. Bremner's experience points him out as the best man; and unless Mr. Brunel will give me a plan of his own to go to work upon, and tell the Directors I am to incur expense, and go to work, the sooner Mr. Bremner comes the better."

However, on the 11th of May the ship was raised 15 inches, and stood up nearly all she rose. Capt. Claxton says, "I have now no fear for her, if we are but blessed with fine weather and smooth water. All my shoots or stages discharged their loads beautifully, and at low water all hollows were filled up, ramming the under stones well down first, and making room for others. We must have now more than 500 tons under her. I have a chain well under her, and well aft too. At this moment we are 2 feet higher than we were a month ago. * * * * To-day's success induces a belief that we might succeed by the tightening process alone."

On the 13th she was still further lifted $3\frac{1}{2}$ feet, the tide having risen to 15 feet, and every thing was looking cheering; the night, however, of that day severely shook their hopes. On the 14th he writes,—"A gloomy night was the last. I was compelled by the weather to decide that nothing should be tried to-morrow, and the pumping hands not taken on. You may suppose how I had to struggle with myself, seeing the tide was sure to be a good one; but with rocks so close, I dare run no risks. We let the water in, but the tide rose rapidly, and with such a swell that the ship was soon in motion, and working more than she ever had done since the gale of November which shifted her position. One consequence is that a new hole (perhaps several) has been made just abaft the foremast bulk-head, and through it, or them, hundreds of tons of sand have been forced into the ship; and through a piece of neglect, into which it is of no use at this distance of time to inquire, the lower hold has so far filled with sand that there is barely room for a man to creep in between the deck of the upper hold and the top of the sand; in point of fact, to its deck the depth of sand is full 5 feet, to be added to which is the sand always under the platform, full 3 feet more, which, running as it does under the boiler and engine-room, as well as under the fore-hold, cannot be less than 200 tons, or with that in the hold probably 500 tons, the whole of the latter portion of which must be removed, or will have to be lifted. The neglect was the not securing down the cover of a man-hole, made in the platform, to examine the damage done by the rock off Newfoundland. * * * * The ship has gone back 6 inches of our gain. I wonder it is not more, and am thankful it is so little. We shall go to work with spirit to get this trouble over, and save a tide for lifting before the springs take off."

On the flood-tide of the 16th she recovered the 5 inches she had lost, a large quantity of sand and about 40 tons of coal having been got out on the previous day.

On the 17th another foot forward, and 4 inches aft, were gained; and on the 19th Capt. Claxton describes the piling up at the bow a shoulder of sand, which, with occasional renewals, kept the ship steady and firm, and prevented her settling again in her dock. This was not removed until it was in the way of the spars, &c., used for lifting.

On the 23rd May, Mr. Bremner arrived, and measures were immediately taken for carrying his plans into effect, without, however, remitting the efforts already in progress.

In a letter dated 17th June, Captain Claxton, in reply to the Secretary of the Admiralty, gives a summary of what had been done up to that time, with his ideas of the prospects of floating off the ship. He states that "since the end of April she had been raised $4\frac{1}{2}$ feet, and relieved of 500 tons of sand and coal intermixed (the whole of which when he commenced was out of reach, being always under water), and 50 tons of machinery, 40 tons more of the latter awaiting a vessel hourly expected. The tightening process has progressed so far that the whole of the after part of the ship, the coal bunkers, the upper fore-hold, and the forward compartment of all, may be considered completed; and on Monday last, on an ordinary spring-tide, she rose a full foot forward, and would have risen higher aft, if it had not been prudent to let the water run there from the engine-room, so as to assist in lightening her forward, where alone the bottom is damaged, and at the same time keep her at rest aft in her present position, under the protection of the breakwater. Under Mr. Brunel's advice, the Directors and Underwriters agreed to call in Mr. Bremner (a gentleman who has had more experience in raising and removing wooden-built ships than probably any other person) to consult with me, when I expressed a doubt of being able to do much more, through her great bearing gradually getting above the reach of the sea, and the lowness of the springs until the end of July. * * * * Thus, by the 15th May, she was gradually raised until she reached 44 inches, 39 of which were maintained, and the largest hole, that under the fore corner of the boilers, was got at and effectually stopped. * * * * Still there are other holes; and, fearful of the responsibility and of the season running away, I requested that Mr. Bremner might be sent to my aid." He goes on to describe the means proposed to be adopted, and the nature of the assistance which the Admiralty (who had offered their co-operation) might afford in the final removal, and conveyance to Liverpool.

On the 15th June he writes to Mr. Brunel,—"There was a bit of sea last night; she kicked off one box, which went with a crash; one spar leg slipped out from the ship, while the other came in at the heel through uneven bearing on the rock under. * * * * To-day the tide failed us a foot, and of course all lifting experiments are over until next springs, when I hope all will be ready, although I doubt it, as we have such a set of carpenters to deal with * * * * We found about a dozen rivets out at low water; there must be, I fear, a largish hole somewhere, as the big one of all is perfectly tight."

On the 18th June, he reports that about 30 tons of sand had got in, during the tides of the 14th and 15th, at the holes he had not been able to find. He expresses a want of faith in the sand-boxes, and his wishes that he had adhered to his original plan of heaving over and stoning up.

24th June.—"Again my ideas are changed with and as variable as the tides. All these neaps we have done nothing towards tightening, the water scarcely ever leaving the bow; so we should have been behind-hand if we had relied on tightening for lifting. Nine boxes are in place; they look formidable, and I am sure Mr. Bremner dares not fill them, nor half fill them. The inch chains by which they are suspended are only equal to 15 tons, and if they are to come back with the ship, the strain will be doubled, the sheaves are so small. I suspect half the spars will go, for some are weak. Mr. Bremner would have had stouter, but they were the best we could get."

Mr. Bremner's preparations could not be completed until the 12th July, on which day Captain Claxton writes,—"A balk gave way last night; the strain then coming upon the after chain, it nearly cut every plank of the outer side clean through, although well shored and three-inch. They will, I fear, go one after the other in the same way.

because the slings or chains are not led up fair, as they might have been, from nearer the bottom through the planks, instead of over them: every box will be strained, even if they hold out; that will be a most serious matter when we come to use them as camels, for which object I think more of them than for lifting, seeing how great the friction must be. * * * * Our first effort with boxes, levers, and screws, was made to day.—9 h. 10 m., she begins to move, the tide having risen to 11 feet, and with those soundings. Now as it required 13 feet before she rose, on the last occasion, it is quite clear that the levers and screws have prized her. I write as events occur, tablets in hand.—9 h. 20 m., up forward 3 inches, boxes beginning to drop, noise awful.—9 h. 30 m., up 5 inches;—9 h. 50 m., up 9 inches;—10 h., up 1 foot;—10 h. 15 m., 1 foot 4 inches;—10 h. 25 m., 1 foot 8 inches;—10 h. 40 m., 2 feet; water $13\frac{1}{2}$, balks bending a good deal; feel certain the boxes will not come up if the ship falls much with the tide;—10 h. 45 m., still rising, a balk on the port side springing; advised with Mr. Bremner, and opened all valves, knocked out the shores of the large one even, to stop her rising; the water flew as high as the deck;—11 h., all now quiet;—11 h. 20 m., it is high water; the tide rose to $14\frac{1}{2}$ feet; the three large screws have an immense pressure on them from the weight of water let in since they were hove, when she was up highest; can they stand when she drops, as she will, a foot or so, for we have nothing but stones to drop under her? The levers are dropped much, and they are down between 3 and 4 feet; if the ship settles a foot, the boxes should come up 2 feet, or something must yield to that extent; it will be an awful trial, as the friction with such small sheaves will be enormous. Mr. Bremner says each screw will hold 100 tons weight on it, pitch $\frac{3}{4}$ inch, worm $\frac{5}{8}$; twelve turns of brass box take all at once on the thread bearing; levers 2 in number, $1\frac{5}{8}$ iron, 14 feet long.—4 h. 40 m., tide begins to fall, foremost starboard balk splits, box gone with a crash; grand, indescribable; after chain, as before, cut through the outer planks;—11 h. 50 m., another balk gone, another crash, another box down;—11 h. 55 m., ditto;—11 h. 57 m., ditto, ditto;—12 h., another; I fear they will all go, for there has been no yielding back; I have chalked chains and balks, and not one inch has one of them come up; they must be made lighter before we raise her higher, or we shall have no camelling from them.—2 P.M., the ship went back a foot, and so stands a foot higher than before, and as we shall begin directly to throw stones under, I think she will not go back further. Five boxes altogether gone, and seven balks; only one chain broke. * * * * It is hard to calculate power; the boxes went down by jerks unpleasantly; they must be holding a great deal, but I doubt their having lifted as much as was expected; but altogether a power of between 300 and 400 tons has been effective, and if the platform be cleared of water, it will be most important: the Bremner appliances have been successful upon the whole; the boxes least so. The levers are holding a great deal of weight, as they have gone down greatly at their outer ends; the forward one is nearly flat, and must be reset."

July 14th.—"We do not try to-day, but are preparing for to-morrow, when, go what may, we must venture all, it being the last tide. She has kept up 9 inches; an immense quantity of stones have been thrown from, and battered under her; shoots are making to drop stones from the deck, a far inferior plan to mine, as the stones themselves have to be carried into, and afterwards lifted with, the ship; spars, wedges, blocks, and falls, however, being in the way, there would not have been room for tilting stages. The Bremners have been actively employed, and I am sure the sequel will show successfully; every thing is prepared."

July 15th.—"Trial No. 2, which I call Mr. Bremner's, is over. * * * * The work would have done probably well enough, if tried yesterday; as it is, the tide cut 1½ foot, and the ship rose only 1 foot and ½ an inch, of which she settled back only 2 inches, when one chain broke, and one box fell, smashed to uselessness."

No further effort could be made till the next spring-tides, but the interim was short enough for the labours of repairing damages and making further preparations.

July 28th.—"A lot of beech trees are provided, averaging a foot through, as shores, varying from 6 to 10 feet long. Chocks for their heads have been attached, with bolts through rivet-holes to the ship's side, care having been taken that the overlap of the plate of the ship bears for the whole length of the chock. Stages or shoots of 3-inch planks, for the heels to slide upon, have been laid on short piles, densely placed, and driven through the sand to the substratum of rocks. Ropes have been fastened to the heels of the shores, as they lay at an angle of about 60°, or varying according to their length; these are led through a block at the gunwale, and the end is loaded with fire-bars, so that when the ship rises, the whole of the shores will be pulled at their heels, and take by a self-acting process their places under the chocks. A large stage of several pieces of beech, doubled transversely, covered and loaded with iron plate, has been got long since under the ship's fore foot; on it were slid large solid wedges; to the fine end, after being pointed under the keel, straps were rove; to them tackles were attached, the heels of the spars of the boxes (themselves being on the rock) taking the outside block; and the falls were taken to capstan, crabs, &c., &c., on deck, and as the ship rose they were hove through until they jambed; they answered well, and when she rises higher will be hove farther through. Another description of wedge, of which a dozen have been made, was landed on stages pointed under the ship's bilge, the lower plank (6 inches thick), or the one which is to slip on the ways, being long enough to pass outside the spars, or about 20 feet to its outer end, where a similar tackle is also attached; the inner block also fast to the spars near, and the fall similarly led up to crabs or purchases on deck. These, with the screws forward, are the new contrivances for keeping all that may be gained, always including the stones, many tons of which are piled in three places on each side on deck, ready for dropping down on shoots made for the purpose."

The last effort for raising her took place on the 29th July.—"The ship began rising at 9 A.M., the tide being only $8\frac{1}{2}$ feet; at 9 h. 30 m., she was up 1 foot 1 inch, with $10\frac{1}{2}$ feet of water, the tide having to rise 4, or perhaps 5 feet more.—I recommended caution, so we stopped pumping. She went on rising till we opened the valves to let water in, all except the main one, at 10 h. 30 m., when she had risen 2 feet 4 inches; the shores were planned for $2\frac{1}{2}$ feet, to which she rose slowly until near 11, when she stopped with $12\frac{1}{2}$ feet of tide only, which afterwards rose to 14 feet 1 inch, so that it is clear Mr. Bremner's aids, assisting her own flotation, lifted the ship, and equally clear the tide this day would have done the work for us without any thing, or nearly so, for she never has been so tight. I write at 2 P.M., the tide having fallen 6 feet, the ship having gone back only 3 inches of the gain. The screws had nothing to do, as she sprung up out of reach of them, but good chocks stand on the stage in their stead. * * * * I now hope she will remain as she is, and that we shall find it high enough to make, on the five or six coming ebbs, quite a tight job of the lower hold and platform. The engine-room was very well; it will take a week to secure the large hole for sea; I suppose a full fortnight to get her ready for floating, the 14 boxes remaining in decent order having to be repaired, &c., &c."

July 30th.—"The ship is high enough for all required above the platform, which was so tight that four hand-pumps kept it free. She ought to have only 3 or 4 inches over the skin, if the trench allows the water to drain off; which has been one of our puzzles from the first. I trust you will approve of my having abandoned the bottom and adopted the platform; we know the worst, and must calculate on carrying under it, either in the form of water or sand, or both, about 100 tons. The fact is, the Bremners have well wedged and shored her up, and the stones are rammed so hard she cannot settle back unless something tremendous comes to trouble us. I can see under her about 35 feet from forward. Our rise stands thus: by following your recommendation, $4\frac{1}{2}$ feet; by the aid of Mr. Bremner's contrivances, 4 feet 1 inch; total gain, 8 feet 7 inches. Surely in such a place this is wonderful."

Between this period and the 4th August the process of tightening, sometimes four, sometimes five hours a day, is described as going on almost as comfortably as if the ship were on a gridiron, excepting under the boilers and engines: the shores held beautifully, squeezing the plank they stood on to half its thickness; but with an on-shore wind, the sand bank being gone, some of the wedges on the sea side began to work a little. The boxes, much strained, were taken down to be repaired and covered in at top. The Admiralty were solicited to send the assisting vessels about the 10th instant.

August 5th.—"We experienced a fearful gale, fearful under our circumstances, yesterday; every thing loose alongside, and almost every thing stepped, was driven high and dry, and several boxes greatly damaged against the rocks. She did not feel the blows of the sea so much as before, which of course is to be attributed to her bearing being higher up, and herself more firm and rigid on stones, shores, and wedges, to say nothing of the levers, which were all up to this day doing their duty; but at near high water a great wave sent the port one, made of the spars of the breakwater, so far out of place that not more than six heels remained under the bilge keel; the whole were thrown forward, and would have been unshipped, if the spars of the boxes had not brought them up; it now forms a capital breakwater for protecting her exposed bow."

H. M. steam frigate *Birkenhead*, 556 horse-power, arrived on the 10th; 56 riggers, under charge of Mr. Bellamy, Master Attendant of Portsmouth Dockyard, and 25 men from H. M. ship *Victory*, in all 87 men, including his own boat's crew, were with difficulty brought in a paddle-box boat through a heavy sea to the ship, the *Birkenhead* immediately leaving the bay for shelter.

August 12th.—"I begin to be alarmed for these tides; to doubt our being forward enough for a good trial, as the breeze keeps up, and the boxes have partially or altogether three times been driven among the rocks, or on the beach; and when alongside they get or have got their share of thumping. * * * * * I shall look for vessels if they fail when first tried, although I dread having charge of any in this dreadful bay."

August 14th.—"No go; *Birkenhead* was placed well by Mr. Bellamy, but the tide only rose to $12\frac{1}{2}$ feet, the table giving $13\frac{1}{2}$: so it has been always; when fine, down it goes; when high, it always blows. I have made up my mind to go for vessels, and to have them, for only four boxes were tight enough to be applied, and they only did half their duties. We shall be better prepared next springs, the range of which should be nearly 4 feet more. We must have the 12 boxes, all that are left of 20, doubled and made tight."

The following eleven days were occupied in preparing lashings and chains for the boxes, landing about 30 tons of chains and other materials, doubling and strengthening the boxes, shoring the *Margaret* and *Betsy*, and placing spars for them to come under, to assist the lifting; and preparing and trying the pumps, 28 of which were to be worked by 2 men, 6 by 4 men, and 2 by 10 men. To work them effectually would require 200 men. H. M. steam frigate *Scourge*, 420 horse-power, had arrived, and the officers and men added their willing and able assistance, as did also those of the *Birkenhead*.

On the evening of the 25th (the full moon fell on the following day) a trial was made to heave the ship off, and she was moved 26 feet; but the water came in alarmingly, over-leaking 16 pumps in the engine-room. The *Betsy*, carrying full 70 tons, broke away from the shores, and the attempt was abandoned for that night, every one being much exhausted. The only assistance on this occasion from H. M. ships was the use of men to heave and pump.

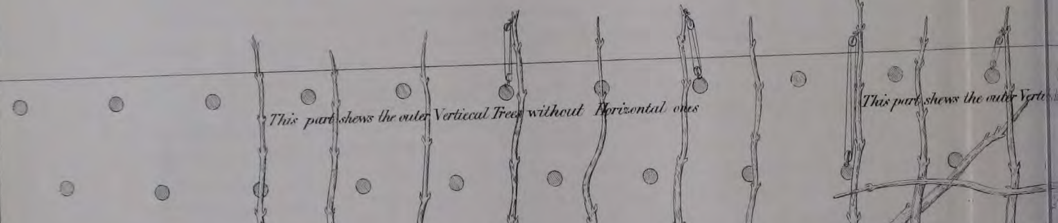
On the 26th the attempt was renewed: all the men that could be spared from the *Scourge* were brought on board by her Commander and First Lieutenant. As soon as the tide reached 12 feet, the signal was made to heave, but the boxes were ill-secured, and at the most critical moment, the *Margaret*, carrying over 100 tons, slipped from her shores. The ship had moved 5 feet. There was, however, no despondency, all applying themselves vigorously to repair disasters and get ready for the next day's tide.

On the 27th the *Birkenhead* was again placed, and as soon as the tide reached 12½ feet, the signal was made to heave. Previously, however, while 50 men were digging the trench, which every where, except just under the stern, was nearly 2 feet deep, Captain Claxton was struck by seeing it did not deepen at that spot where he placed the men as thick as they could work, who duly managed to scrape up small quantities of shingle and sand: seeing they got no lower, he went in and found a solid rock, with about 5 inches of water over its top, of the existence of which the whole of the labourers could not but be aware: he traced it to the ship's stern-post, which, whilst drawing 26 inches, rested on a portion and butted against a shoulder, about 6 inches high: "it thus became certain that it was the rock which brought the ship up after the first move, which prevented her moving more than 5 feet on the last trial, and which the Irish looked to as a certain means of preventing the 'repeal of a union' by which they had so greatly benefited, that over it the ship was to be lifted 15 inches before there was a possibility of her being got away." Additional leakage had been caused by moving the ship the day before from her supports, the iron plates opening out for a few feet about ½ an inch from the fore bulk-head on each side; the boiler-makers, however, succeeded in stopping it, in readiness for the coming tide, which produced the closing triumph.

August 27th.—"Huzza! huzza! you know what that means. I got more men at the pumps; Captain Fisher, most kindly, as he always has done, came to my assistance with 20 coast-guard men; they worked one of the large pumps splendidly, and at one time she was drawn down 4 inches in half an hour, showing that with good pumping we could even then beat the leaks. The weather was beautiful, the bay crowded with equipages and people; and having to look even for a higher tide on Saturday, I made up my mind to stop her at the edge of low water, and then examine and stop up all that might discover itself. The tide rose to 15 feet 8 inches; she rose therefore easily over the rock which brought her up yesterday, but she even then was clear of it by only just 5 inches, which shows how near a squeak we had. It was a most anxious affair, but it is over. I marked 170 yards in the sand and on our warp, and at that extent I stopped her, hoisting the signal, 'Avast heaving'—'Let go halsers'—'All's right.' It blows fresh from the southward, but there is not sea enough to disturb the sand, so

Breakwater Protection to the **GREAT BRITAIN**, *of Fagots, Beech Trees, a*
executed under the Superintendence of Capt. Claxton, R.N. between the end o
weather, so trying as to check the progress of fagotting and to compel the
The combined System relieved the Ship during Seven severe Gales, including

drawn



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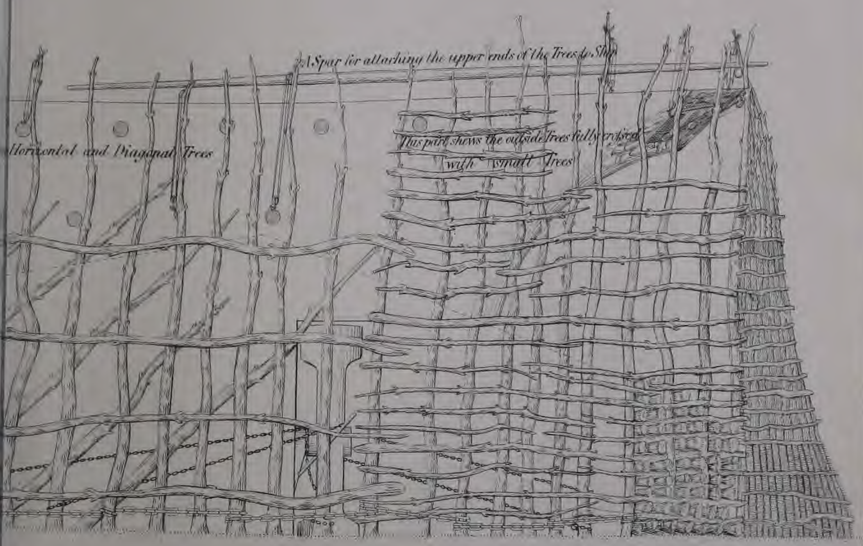
John Weale 59, High Holborn

PLATE 2.

lateral Fir Poles, recommended by Mr. Brunel, and
cr. 1846 and the end of January 1847 in very trying
stitution of Poles &c. with Mr. Brunel's acquiescence.
se of the March Equinoxes which were dead on shore.

Alexander Bremner, C.E. June 25th 1847.
assisting his Father & Capt. Claxton,
in removing the Great Britain.



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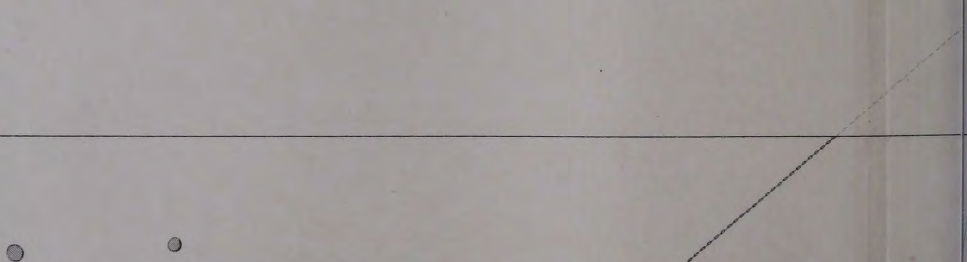
Breakwater Protection to the **GREAT BRITAIN**, *of Fagots, Beech Trees, and lateral Fir Poles, recon*
executed under the Superintendence of Capt. Claxton, R.N. between the end of Decr. 1846 and the end of
weather, so trying as to check the progress of fagotting and to compel the substitution of Poles &c.
The combined System relieved the Ship during Seven severe Gales, including those of the March Equinox

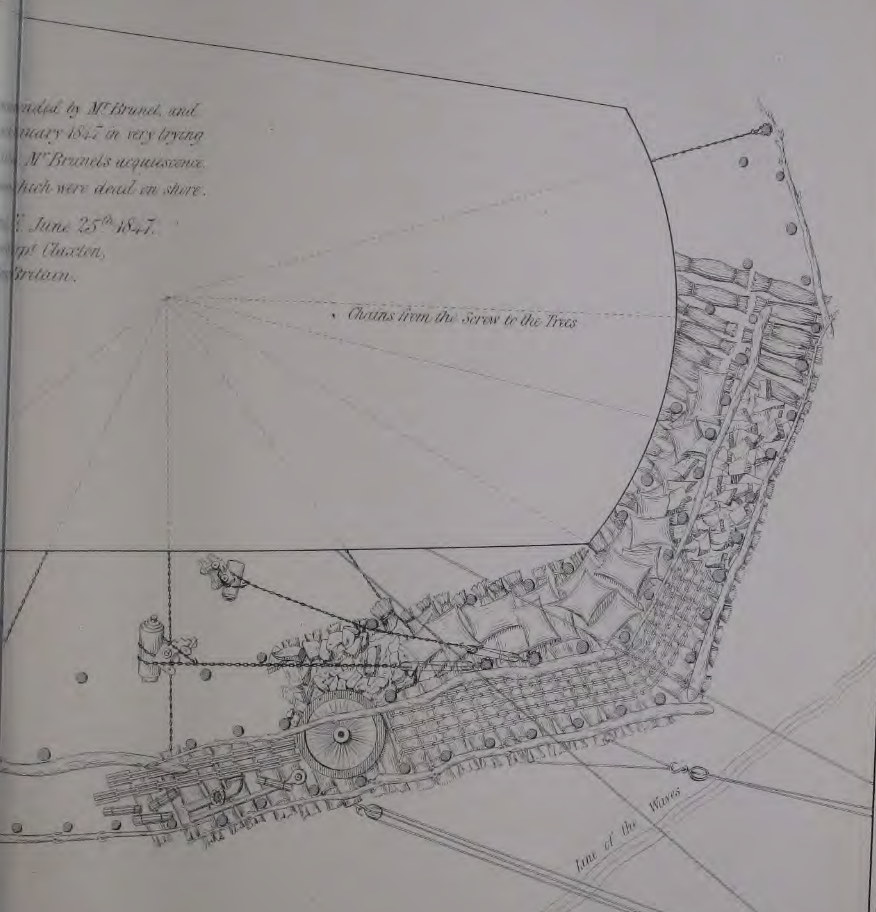
drawn by Alexander Bremner,
assisting his Father
in removing the Gre

PLAN



John Weale, 59, High Holbo

PLATE 3.



C.F. Cheffins, Lithogr. Southampton Buildgs. Holborn.

49.

we shall be quite upright, and we shall stop much. I have no doubt to-morrow we shall be free!"

At low water a clear view was obtained of every part of her bottom, except the flat between the bilge keels; and several rivets, being found broken, were repaired. At 11 P. M. she was thoroughly afloat; but it was 4 A. M. of the 28th before she was fairly in tow by the *Birkenhead*, during which time she had leaked so much as to make their situation perilous. After three hours' hard labour, the pumps had freed her considerably, and the water gained but slightly. It was intended to lay her on a hard bank within Strangford Lough; but when they were very near the entrance, a fog came on, so dense as to prevent either ship seeing the other, and the attempt would have been dangerous in the extreme. Belfast, the next nearest port, was therefore steered for, on a mud bank within which she was placed aground about an hour before low water, and the men relieved from pumping.

By the aid of 200 labourers, all the water was pumped out of her before morning, and with 140 of them on board, and with others, amounting in all to about 300 people, a start was made at 11 A. M. for Liverpool, which was reached at the rate of about $6\frac{1}{2}$ knots an hour, just at the commencement of a gale which lasted a fortnight.

The rescue of this ship from her stormy prison stands conspicuous as an engineering and maritime triumph; and the professional interest that cannot fail to attach to the means by which it was accomplished, will, it is hoped, be admitted as my apology for the free use made of the valuable pamphlet from which the foregoing extracts are taken, more especially by readers abroad, to whom that narrative may be inaccessible. Less could not have conveyed an approach to an adequate comprehension of those means, and of the difficulties that attended them; difficulties which appalled at a critical moment the hearts of all but Captain Claxton,—rendering more distinguished the prompt judgment and intrepid resolution with which that Officer directed and superintended the operations throughout.

MONT^Y. WILLIAMS,
Captain, Royal Engineers.

Royal Dockyard, Pembroke,
24th December, 1847.

IV.—*Explanation of the Battle of Meeānee.* *By Major-General* Sir William Napier, K. C. B.

TO THE EDITOR OF THE PROFESSIONAL PAPERS.

Guernsey, September 10, 1847.

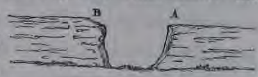
Sir,

Major Waddington's account of the battle of Meeānee, in the ninth volume of the Engineers' Professional Papers, is, on some points, so much at variance with my account of the same action, that I must earnestly request the favour of having the following observations placed in the next volume of the Professional Papers of which you are Editor: and as I have the greatest respect for Major Waddington's services, you will, I hope, find nothing in my observations unmeet for the general tone and sober propriety of your publication; and some portions of them may perhaps be considered interesting to military men.

Major Waddington states the British forces to be about 3000 strong. They were so perhaps on paper, ten days before the action, and including sick; but I am assured by Sir C. Napier, that for the reasons mentioned in my work, not more than 1700, including officers, were engaged in the battle; and this enumeration is the result of a very careful examination by the Staff of the General, made after the action, to correct the dispatch, which, written in the confusion of the moment, was certainly inaccurate. This result has also been recently confirmed by the assurance of two officers of the 22nd regiment, and one of the Company's service, who were present in the fight.

Major Waddington states that the top of the Shikargah wall was at first thickly studded with matchlock-men, but on the advance of the line was abandoned. Sir C. Napier writes as follows:

"The Beloochees were not crowded on the wall, which was only a foot thick; one man sat astride on it, firing at us, I believe at me, and that he was a marksman, put there as knowing me. He had only time for three shots, or so; for seeing how he fired at me and my Staff, I told some of the 22nd to shoot him, and he fell like a lump of lead on our side. We had seen matchlocks handed up to him; I swept the whole wall well with my telescope before we advanced, and while under the cannonade, and there was not a man but him on it. I saw through the opening A B obliquely, my light passing A to a good way behind B; and I ascertained there was no scaffolding to enable them to fire over, no loopholes to fire through. It was this made me think the wall was purposely broken to let them sally out on our rear. When I was satisfied there were neither loopholes nor banquette, I ordered the advance. I was so particular, that, though my horse, Red Rover, stands steady, I could not satisfy myself while on the beast's back; and I dismounted, and again steadily swept the wall and examined the breach.



"I did not think of sending on Tew, till we were advancing, and I was thinking of how to deal with them, if they rushed out from the wall: many things came like flashes across my mind. I was unsatisfied at this moment; the fire from the matchlocks in front was heavy, and no time to lose. Suddenly the idea came into my head to *attack them through the wall, as the best check*, and I ordered one company, about 60 or 70 men; I could not spare more. I told Tew, he must defend the entrance to *the last*; or, rather I sent him that order, for the 22nd had got to firing: there was confusion, and matters had put on a very dangerous aspect. Tew beat them back, and he found plenty there, and fell about 60 yards within the gap; but his men *held on*. He could not have gone further; thousands filled the wood, upon whom, soon afterwards, we opened a nine-pounder through the wall: it told tremendously, and relieved Tew's men, who would otherwise have been sorely pressed; yet I could have aided them with guns, had they been driven back."

Major Waddington would seem to imply, for I am not quite sure of his meaning, that the close fighting did not last more than one hour.

Upon this point I have consulted the three officers alluded to before, having first requested them to read the Major's account: they were unanimous that he was mistaken, and gave several strong facts within their own peculiar knowledge in support of their view; and from Sir Charles Napier I received the following remarks:

"The battle began at *nine o'clock*, and we formed on the opposite bank of the Foolailee at *one*, firing still going on. What the dispatch says was taken from all our watches."

Now Major Waddington says the opposite bank was gained at half-past one, thus giving an additional half hour; and as the lowest calculation gives four hours' fighting, the greatest part must have been spent in the close conflict, thus confirming my account, which gave three hours and a half of rugged battle.

Major Waddington says—"By some misconception of an order, the 1st grenadiers N.I. faced to the right-about, and retreated some distance before their officers could rally them." Sir Charles Napier says emphatically, "They went about by Clibborne's order; but there were a thousand causes assigned at the time for their conduct."

Major Waddington says—"Lieutenant-Colonel Pattle[1] had not received the General's order to charge; but seeing the necessity of checking the enemy's movement, and being urged by Captain Tucker, of the 9th Bengal cavalry, after some hesitation, permitted the cavalry to act."

This statement, qualified by the acknowledgment that it was hearsay, would give all the merit of the conception of that brilliant movement to Lieutenant-Colonel Pattle and Captain Tucker, and all the merit of the execution to the 9th cavalry. Major Waddington, however, only writes, as he says, from the information he received from others: he was, I believe, close to the General all the action, and carried no orders to any other part of the field. He has been misinformed on this interesting portion of the action. Sir Charles Napier informs me he sent three officers one after the other with the order, fearing death might intercept it. Those officers were Lieutenant-Colonel

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[1] (*Copy.*) "Poonah, 6th March, 1844.

"MY DEAR GENERAL,

"Your letter of the 28th ultimo I received last evening.

"As regards Colonel Pattle ordering the cavalry to charge of his own accord, I can affirm such was not the case. I received orders from you to desire the cavalry to charge. I rode up to Colonel Pattle, and delivered *to him distinctly and loudly* (he being rather deaf) the *order* in nearly the following words: 'Colonel Pattle, you will advance as quickly as possible with your cavalry, and charge the enemy on their right;'—and at the same time I pointed out to him the direction with my hand. His reply was, 'Very good,' or 'Very well.'

"Thompson had been before me, but I don't know if he delivered the orders to Major (now Colonel) Storey, or Colonel Pattle; but to the latter officer I gave the order distinctly, and he immediately acted upon it.

"I have made inquiry of Lieutenant Brennan if he conveyed any order to the cavalry on the 17th February: he says he did not.

"Believe me, &c.

(Signed) "P. M^c PHERSON,

"Lieut.-Colonel, H. M. 17th Regiment.

"Major-General Sir C. Napier,
Governor of Scinde."

M'Pherson, Captain Pelly, and Captain Thompson; and their letters declaring this fact are in existence, but he had only that of Captain Thompson at hand to send to me: it is given below.

As to the charge being led by the 9th cavalry, it is true, and nevertheless the irregular Scinde horse did perform the part assigned them in my work, namely, attacking the enemy's camp, and spreading confusion and terror in their rear after passing the Foolailee; for the Bengal troopers, while in the dry bed of that river, turned a little to the left, and thus the Scinde horsemen passed them, and fell on the camp.

Captain Thompson's Letter.

"Simla, 22nd May, 1844.

"Colonel Pattle was mistaken when he told you he received no order to charge at Meeānee; for you gave the order to me, and I met the Colonel about half-way between the cavalry and infantry: he was *riding towards the latter*, and asked me how they were getting on? I made no reply, but told him your order: he said, 'Tell Storey,' and I rode on. I told Major Storey, and *saw* the 9th cavalry advance, and remember Garrett beginning to trot, when Storey called out, 'Gently, Garrett! Gently!' On my return I met M'Pherson, who asked me if I had given the order; and I think he rode on to the cavalry: so there can be no mistake about the Colonel having received the order.

(Signed) "H. THOMPSON."

Major Waddington, speaking of the enemy's loss, says—"The enemy left upwards of four hundred dead in the bed of the Foolailee, and there were probably as many more in different parts of the field, and the Shikargah, killed by the artillery and cavalry."

The officers of the 22nd and Company's Service who read this at my request were unanimously and decidedly opposed to its correctness; but the following observations by Sir Charles Napier will probably be deemed the best authority; and it is to be remembered that the detailed returns made to the Ameers by the different tribes of the loss of each in the battle, fell afterwards into the English General's hands, and gave an amount of eight thousand!

"As to the dead, Waddington is decidedly wrong. Two officers, I think Pelly and Fitzgerald, counted *four hundred bodies* within a semicircle of *fifty paces' radius*, where I chiefly stood, near the little nullah running into the bed of the river. Now to the *left* of that were all those killed by the 12th regiment, by the grenadiers, and by the cavalry; a pretty good lot! The ground was covered by the dead! Then again, in the Shikargah, no one can tell, it was a dense wood,—the artillery and Tew's men must have killed many, but no one could count the whole, or even see them! Waddington did not, but 400 may have been the number there; far more, people said at the time. I did not see them; I never entered the wood. The cavalry killed none in the wood; no horse could go three yards in it."

Having thus noticed the leading points of Major Waddington's account of the battle, it may be that you will not object to the following remarks of Sir Charles Napier as to his reasons for attacking on so contracted and well occupied a front, instead of turning the Ameers' line of defence by his right.

"I have examined all our surveys; there is no mistake, the front was rather more than 1200 yards: your plan in the 'Conquest of Scinde' is perfectly correct. The front between Kotree and the wall is 700 yards; but that was *our front*, not the Ameers'. They outflanked us far: look at Jacob's report of what he found on the ground, marked in your map as 'impassable for cavalry.' On the enemy's left also. Not only did he occupy the Shikargah; but I have since heard his people reached to a bend in the river, which there runs about a mile west, and then wheels north.—— I had moved with the 9th cavalry to my right before the battle, and no doubt our advance was well watched from the wood, and troops prepared to receive us: it is hardly possible to doubt this. On reaching the wood I determined to flank it. I dared not enter such *a defile;* thick woods on both sides of the river bed; wherefore I halted my advance, and filed off to the left. No one can believe that such skilful men, in taking up their position, would have left the wood unoccupied, and allow me to march quietly through the bed of the river and turn the left flank of their ground at Meeānee. It is evident, that, had I been mad enough to march that way, I should have found myself between two deadly fires of matchlocks from both banks, and have been defeated. Each bank is a parapet; my cavalry would have been useless; and the wood was so dense that our infantry must have been broken, and the affair quickly finished: each man singly would have had a host upon him with shield and sword."

W. NAPIER,
Major-General, Author of 'The Conquest of Scinde.'

V.—*The Doctrines of Carpentry examined, in their Application to the Construction of a Roof. By Lieut.-Colonel* CHARLES WADDINGTON, *C.B., of the Bombay Engineers.*

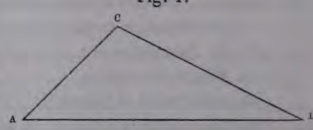
CONTENTS.

A PARTICULAR CONSIDERATION OF THE STRAINS ON THE TIMBERS OF A TRUSSED ROOF, AND OF THEIR PROPER SCANTLINGS.

1. A truss, in carpentry, is a combination of three or more timbers, so framed together as to be at rest one with another, while supporting their own weights and any extraneous forces.

2. The most simple truss is composed of three timbers, of which, in fig. 1, two, A C and B C, are by their own gravity compressed, while one, A B, is extended.

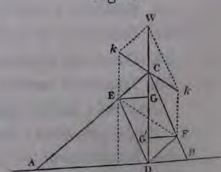
Fig. 1.



And in a truss of more than three timbers, they will not be at rest, unless it be parted into three solid figures, or the timbers be kept in equilibrium by equal opposing forces.

3. If a weight be suspended at the vertex C, of a truss A C B, figure 2, the stresses at A and B will be in the directions C A and C B, and the opposite thrusts at A and B, in the directions D A and D B, will be equal.[1]

Fig. 2.



For let the vertical line C D represent the weight, and draw D F and D E parallel to A C and B C, and E G, G′ F parallel to A B.

[1] Tredgold's 'Carpentry,' 2nd edition of 1824, Article 17.

The direct force C D is thus resolved into the oblique forces C E and C F, acting in the directions C A and C B;[2] and G E, G′ F represent their opposite effects at the points A and B,[3] which are equal, because the triangles C E D and C F D being each half of the parallelogram C E D F, are identical,[4] and G E, G′ F form equal angles with their common side C D, and are therefore equal.

4. The vertical pressures at the points A and B will be inversely as their distances from the line C D; that is to say, C G, which represents the vertical pressure at A, will be to C G′ or G D, which represents the pressure at B, as B D is to D A; for by similar triangles,

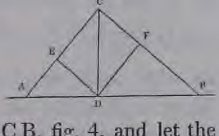
C G : G D :: (C E or) F D : E A,
also B D : D A :: F D : E A;
therefore C G : G D :: B D : D A.

5. The line $k\,C\,k$, parallel to E F, will be the direction of the opposite pressures at C, and k C, k C will express their respective equal amounts; for the re-actions to pressure at A and B are expressed by E C and F C, while the weight causing that effect on each beam is $w\,C = \frac{CD}{2}$; and the results of these opposing forces are the diagonals of their respective parallelograms, which are k C, k C, and which are manifestly equal and in a straight line, because the lines E F and C D mutually bisect each other.

6. And where the angle C is a right angle, and A B horizontal, fig. 3, the forces C E and C F will be as the lengths of the opposite beams C B and C A.

For the triangles D E C or C F D, and A C B, are in this case similar, and (E D or) C F : C E :: C A : C B.

Fig. 3.

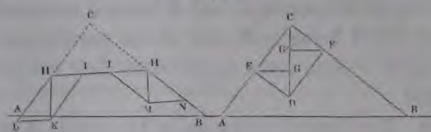


7. Let there be any two identical trusses A C B, A C B, fig. 4, and let the beams A C, B C in one of them be cut off at H, H, and there supported by a cross beam, the points H, H being loaded in such proportion as to keep the truss A H H B in equilibrium in the absence of other forces; and let a third weight, equal to the sum of the two at H and H, be suspended from C in the other truss; then will the strains produced in the two trusses by those weights be in every respect the same.

[2] Hutton's 'Mathematics,' 7th edition, vol. ii. p. 138, Article 41. [3] Idem, Art. 42.
[4] Idem, vol. i. p. 283. Theorem 22.

Lay off, on the line H H, two equal lengths H I, H I, to represent the opposite strains on that beam, which, by the condition of the truss being in equilibrium, must be equal; and complete the parallelograms H I K L and H I M N, to express likewise the oblique, and, by their diagonals, the vertical strains or weights.

Fig. 4.

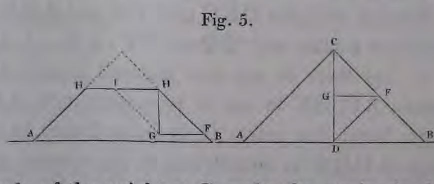


And as it is stipulated in the proposition, that the weight at C in the one truss shall equal the sum of the two weights in the other, make C D = H K + H M, and draw D F, D E parallel to A C, B C, and E G, G′ F parallel to H H.

Now the triangles H K L and C G E in the two trusses are similar, as also the two triangles H M N and C G′ F; and we have H K + H M = C G + (G D or) C G′, that is to say, the sum of the vertical sides of the triangles H K L, H M N, equals the sum of the vertical sides of their respectively similar triangles C G E and C G′ F. It follows that the sum of the sides L K, M N must also equal the sum of their corresponding sides E G, G′ F; and as L K is = M N, and E G = G′ F (Art. 3), the triangles which were seen to be similar must be identical, having their remaining like sides also equal, namely, H K = C G, H M = C G′, H L = C E, and H N = C F. But the sides of these triangles represent the strains, which are therefore identical in the two trusses.

8. When the slope, whatever it be, of the two opposite beams is the same, fig. 5, and the connecting beam horizontal, the stress at H or H caused by a weight $HG = \frac{CD}{2}$, will equal the stress at C caused by the whole weight C D, or with equal weights, the stress at H would be double the stress at the more acute angle C; for it is by acting with this double stress that the weights at H, H, being each of them in this case half only of the weight at C, make the strains in the two trusses equal, which, as shown in the preceding Article, they will and must always be.[5]

Fig. 5.

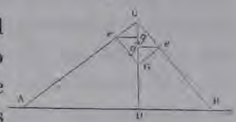


[5] This conclusion has escaped Mr. Tredgold's observation; for he states in his 'Carpentry,' Art. 184,—"The pressure on a principal rafter is in direction of its length, and is in proportion to

9. If a weight be divided into any two portions, and one portion equally distributed throughout the beam A C, and the other throughout the beam B C, of the truss A C B, fig. 6, then will the opposite horizontal thrusts be equal, and the halves of what they would be if the whole weight were suspended at C.

Let the whole weight be represented by C D, which bisect at G, and complete the parallelogram C *e* G *e*.

Fig. 6 *a*.



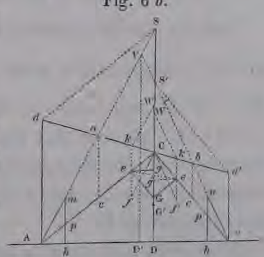
Now the weight on A C being equally distributed over that beam, may be considered as collected in two equal portions at the points A and C; and in like manner the weight on the beam B C may be taken as being equally divided between B and C.

We have then half of the joint weight acting at C, and represented by C G, and its effects by the parallelogram C *e* G *e*, while the other moieties of the weights, collected at A and B, produce no horizontal strain. The whole horizontal strain therefore is expressed by *g e*, or its opposite and equal *g′ e* (Art. 3), and it is half of the horizontal strain due to C D, being in proportion to that strain as C G to C D.

10. Also the vertical pressures at the points A and B will be each equal to half the weight of the adjoining beam, *plus* half the pressure due to the sum of the weights of both beams, if suspended at C; and they will be inversely proportional to their distances from the vertical line V D′ drawn through the intersection of the lines of direction of the strains on A and B.

Divide C D into two parts at G′, the weight on the beam A C being expressed by C G′, and that on the beam B C by G′ D.

Fig. 6 *b*.



Now half of the weight on the beam A C, expressed by $\frac{C\,G'}{2}$, rests on A, and exerts there a direct vertical pressure to that amount; and half of the weight on B C, expressed by $\frac{G'D}{2}$, exerts a direct vertical pressure to that amount on B. And the remaining half of the joint weight acts at C, being expressed by C G, and causes at the points A and B the vertical

the magnitude of the roof; but this pressure does not bear the same proportion to the weight when there is a king-post as when there are queen-posts."

pressures $C g$ and $C g'$, which are the halves of the vertical pressures that would be produced by the whole weight C D.

Lay off h A and h B, each equal to $g e$, then $p h$ is $= C g$, and $p' h = C g'$. Also make $m p = \frac{C G'}{2}$, and $n p = \frac{G' D}{2}$. Thus $m h$, $n h$ will express the whole vertical pressures at A and B, and the hypothenuses m A and n B will represent the effect and direction of these forces combined with the horizontal forces h A and h B. Prolong the lines A m and B n till they meet at V, and drop the line V D′ perpendicular to A B; and $m h$, the vertical pressure on A, will be to $n h$ the vertical pressure on B as B D′ is to D′ A; for by similar triangles,

$$\begin{aligned} m h : (h\,A \text{ or})\ h\,B &:: V D' : D' A, \\ \text{also } n h : \qquad h\,B &:: V D' : B D'; \\ \text{therefore } m h : n h &:: B D' : D' A. \end{aligned}$$

11. If, after prolonging the lines D C and A V till they meet at S, we lay off vertically a length A d = C S, and a length B d' = C S′, then will a straight line drawn from d to d' pass through C, and be the direction of the equal and opposite pressures at that point, k C and k C, which are thus found.

The re-action to pressure at A is expressed by f C, drawn parallel and equal to m A, but the weight sustained by the beam A C is W C made = to C G′; and completing the parallelogram, k C is its diagonal, expressing the joint effect of these two opposing forces; and the opposite diagonal k C is found in like manner by making f' C parallel and equal to n B and W′ C = G′ D.

Now by similar opposite triangles, $e f$ is $= m p = \frac{C G'}{2}$; and as $k f$ is = W C or C G′, therefore $k e$ must also be $= \frac{C G'}{2} = m p$; and by similar triangles, S C : A C :: $m p$: A p; or by the substitution of other equal lines, d A : A C :: $k e$: e C, proving that the triangles d A C and $k e$ C are similar, and consequently that the straight line d C passes through the point k; and in like manner it may be shown that the straight line C d' passes through k on the opposite side of C.

Moreover, that d C d' is one continued straight line thus appears. Draw the line $e e$, which, being a diagonal of the parallelogram C e G e, will bisect the opposite diagonal C G; but it also bisects the lines $k e f$, $k e f'$, which are at equal distances from C G, and the sum of whose lengths is 2 C G. Therefore k C k must be a straight line, and k C, k C the opposite strains, equal; and as the points k, k have been shown to be in the direct lines d C and C d', the line d C d' must be one continued straight line.

12. The vertical lines $a\,c$, $b\,c$, dropped from the points a and b, where the lines of direction of the strains on A and B cross the line of direction of the strains on C, will bisect the beams A C, B C.

For a is the centre of the parallelogram S C A d, and the vertical line $a\,c$ being parallel to its side S C, necessarily bisects the adjoining side A C; and in the same manner b is the centre of the parallelogram S′ C B d', and the line $b\,c$ being parallel to the line S′ C, bisects the side B C.

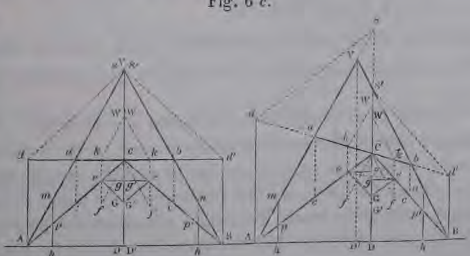
13. And the same results will still be found, if, instead of considering the weights to be divided between the points A and C and B and C, we suppose them collected in the centres of gravity of their respective beams, which, the weights being equally distributed, are the same as their centres c, c.[6]

For on this supposition the beam A C must be viewed as being kept at rest by the action of three forces:[7] 1st, By its own weight, concentrated at c, and acting in the vertical line $a\,c$. 2ndly, By the resistance to pressure at A in the direction A a. 3rdly, By the resistance to pressure of the opposite beam B C, exerted in the direction $d'\,d$, and meeting the other two forces at a.

And in like manner the beam B C is to be viewed as supported by three forces meeting at b.

14. If a truss A $a\,b$ B were loaded at a with that portion of the weight expressed by C G′, and at b with the portion G′ D, it would be in equilibrium, and the strains at A, C and B would be the same as in the truss A C B with the same weights. In other words, a and b are the points of action of the two weights: or the effects at A and B will be the same as if the whole weight were, in a truss A V B, suspended from V, the point of action of the joint weight;[8] and

Fig. 6 c.



[6] Hutton's 'Mathematics,' vol. ii. p. 197, Art. 226.

[7] Idem, Prop. 31, Art. 168; Gregory's 'Mechanics,' vol. i. Art. 106; and Tredgold's 'Carpentry,' Art. 33.

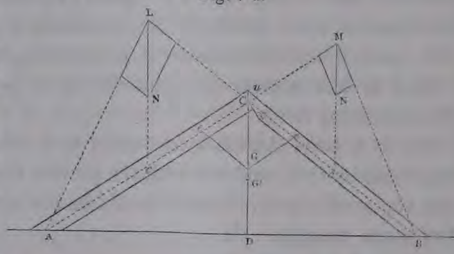
[8] For the proof of these effects being identical, see Art. 7.

when the weights and slopes of the opposing beams are equal, V D′ will be equal to 2 C D, and in the same line.

15. But when the weights are considered as being collected in the centres of gravity, it is requisite that the directions of two of the three supporting forces be known, in order to find the strains.[9] This is the case when the weights and slopes of the opposite beams are equal, for then the direction of their mutual resistances to pressure at C is horizontal, and the intersections of that line with the vertical lines of pressure passing through the centres of gravity give the points of action *a* and *b*.

16. When, however, the slopes or weights or both differ, let the beams be made to meet at C, figs. 7, in two planes, V C, C *u*, perpendicular to their respective lengths: the beam A C will thus exert a pressure on B C in the direction L B, and B C will press on A C in the direction M A,[10] and the vertical lines drawn through the centres of gravity *c*, *c* will meet these lines of pressure at the points L and M.

Fig. 7 *a*.



Make $C\,G = \frac{C\,D}{2}$ as before, and complete the parallelogram C *e* G *e*. Lay off L N = C G′, to represent the weight of the beam A C, and M N = G′ D, as the weight of B C, and complete their respective parallelograms on the lines L A, L C and M B, M C. Join D *e*, which will be parallel to M B, because these lines respectively bisect the corresponding sides of the similar and parallel triangles Y D C and C B Z.

[9] Articles 13 to 19 may be read or passed over *ad libitum*. They are here introduced to show that the usual treatment of the subject (conceiving the weights as collected at their centres of gravity) leads to the same conclusions as when the weights are supposed to be collected at the extremities of the beams, and that no changes in the planes of jointure of its component parts will alter the strains in a truss. The method of demonstration pursued in Arts. 9 and 10, of considering the weights as lodged in the extremities, instead of in the centres of beams, is more simple and comprehensive than the latter, which requires to be varied in its application to different cases, in some of which, as in Arts. 16, 17, it is very tedious.

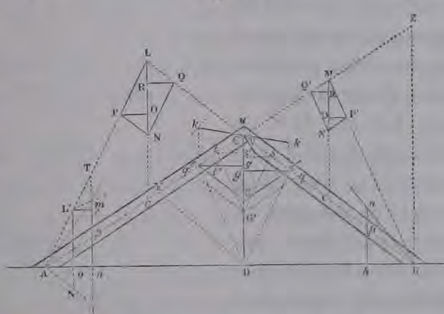
[10] Hutton's 'Mathematics,' vol. ii. p. 141, Art. 143; and Tredgold's 'Carpentry,' Art. 34.

Join also D e', which, for a like reason, will be parallel to L A, and draw G$'$ s and G$'$ t parallel to D e' and D e. (See fig. 7 b.)

Now we have L P with M Q$'$ representing the pressures on A and L Q with M P$'$ as the pressures on B. Also R Q + (O P$'$ or) Q$'$ R will be the horizontal thrust at B or at A, and will be equal to $e\,g$; for by identical triangles, R Q is = S$'$ S and Q$'$ R = $e\,t'$, but S$'$ S is = t S$'$, because the lines G$'$ t, G$'$ S bisect the sides C q, C q of the opposite equal triangles of the parallelogram C q G$'$ q, making S$'$ S and t S$'$ proportional to the equal perpendiculars, which may be dropped from q and q on their common side C G$'$, and therefore equal to one another. Thus R Q + Q$'$ R are equal to $e\,t' + t$ S$'$ = $e\,g$.

Lay off then A h and B h, each = $e\,g$ or $g'\,e'$, and make the vertical force $m\,h$ = L O + M R, and the vertical force $n\,h$ = L R + M O; and the compounds of these forces m A and n B will express the amount and direction of the resulting pressures at A and at B.

Fig. 7 b.



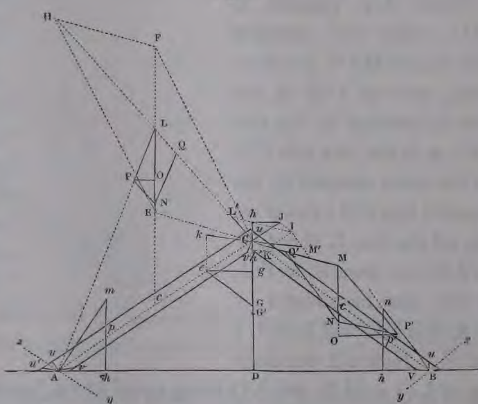
Draw A U parallel to B C, then the triangles T A U and D e' C are identical; and as C D in the one is bisected by the line e'G, so is the like side T U in the other bisected by the parallel line C A; and if we lay off the line L$'$ N = C G$'$ or L N and parallel to T U, it will also be bisected by C A, and L O will be = L$'$ o = $r\,h$. Now $m\,h$ was made up of L O + M R, and L O being equal to $r\,h$, leaves M R = $m\,r$; and as Q$'$ R is equal to ($e\,g$ − R Q = A h − A o =) L$'$ r, m L$'$ must be parallel to C A, and $m\,p = \frac{\text{L}'\text{N}}{2}$ or $= \frac{\text{C G}}{2}$; and in like manner $n\,p'$ will be found equal to $\frac{\text{G}'\text{D}}{2}$.

The resulting strains on the points A and B in this truss have thus been shown to correspond with those detailed in Articles 9 and 10. The strains at C must as a necessary sequence be those described in Art. 11, and may be found as therein laid down, or by making $k\,e$, $k\,e'$ equal to $m\,p$ and $n\,p'$ respectively.

17. Now if the beams A C, B C, fig. 7 *b*, were made to meet in a single plane at C, they would not remain at rest unless that plane were perpendicular to the line of strain *k* C *k*; but when the beams meet in two or more planes, it is not requisite for their equilibrium that these planes should be perpendicular to their lengths. There are other planes at which the beams meeting may yet be at rest.[11]

Let A B C, fig. 8, represent the same truss as in fig. 7, but differing in the planes of meeting *v* C, *u* C of the opposite beams. Draw the lines M E, C F perpendicular to those planes. Here the beam B C rests entirely against the plane C *v*, and exerts no pressure upwards against C *u*, but the beam A C presses upon both planes, and H C is the direction of this joint pressure, being the diagonal of the parallelogram F C E H, the sides of which are perpendicular to the planes.

Fig. 8.



Lay off, as in fig. 7 *b*, L N = C G′, the weight on A C and M N = G′D, the weight on B C, and complete their parallelograms, giving as the pressures L P and M P′ on the points A and B, and L Q = L′ C with M Q′ = M′ C at the point C. Compound these two latter forces into I C, and resolve that again into K C and J C. At A make the horizontal thrust *h* A = J *h* + O P, and the vertical pressure *m h* = *h* C + L O, and at B make *h* B = O P′ − K *h*′ (the latter thrust being in the opposite direction to O P′), while *n h* will be = M O − C *h*′, (the latter force tending to lift the beam.)

It is unnecessary to go through another demonstration similar to that in the

[11] But there are some planes which would not support the equilibrium. If the angle *v* C K, fig. 8, were larger than a right angle, the beam B C would fall on A B, unless prevented by friction, the effects of which are not here taken into consideration.

preceding Article, in order to prove that $h\,A$ and $h\,B$ are each equal to $g\,e$, that $m\,p$ and $n\,p'$ are severally equal to $\frac{C\,G'}{2}$ and to $\frac{G'\,D}{2}$, and that $k\,C$ expresses the direction and amount of each of the equal and opposite pressures at C; in short, that the strains remain the same as in the truss A C B, fig. 7.

18. And in like manner it may be shown, that if for the single planes $x\,y$, $x\,y$, perpendicular to the lines of pressure at the points A and B, there be substituted two or more planes[12] at each of those points, such as $v\,A$, $A\,u$ and $v\,B$, $B\,u$, the strains at those points will still remain the same.

19. It thus appears that the demonstrations given in Arts. 9, 10, 11, are of general application, and that no alteration in the joinings[13] of the beams can change the directions of the ultimately resulting strains, as found in those Articles.

20. If a weight $W\,D'$ act at any point C of a truss A C B, fig. 9, the opposite horizontal thrusts will be equal, and in proportion to the horizontal thrusts that would be caused by the same weight being placed at C, as $A\,D'$ is to A D.

Make the weight $W\,D'$ resting on $c = C\,D$, then $c\,D' = C\,G$ will be the portion supported at C, and $W\,c = G\,D$, the portion supported at A; for, on the principle of the lever,[14] the weights on the fulcra C and A are inversely as their distances from the line $W\,D'$, or directly as $A\,D'$ to $D'\,D$, or by similar triangles, as $c\,D'$ to $W\,c$.

Now the weight expressed by G D, and resting at A, is a simple vertical pressure, and the only horizontal strains are those caused by the weight C G acting at C, namely, $e\,g$ and $g'\,e$, which, as shown in Art. 3, are equal; and by similar triangles, $e\,g : E\,G' :: (C\,G \text{ or}) \; c\,D' : C\,D$, or as $A\,D' : A\,D$.

21. Also the vertical pressure at B will be that which would be due to the portion $c\,D'$, suspended at C, and will be to the pressure due to the whole weight, if suspended there, as $A\,D'$ to A D; and the vertical pressure at A will be a part $W\,c$ of the whole weight, bearing the proportion to it of $D'\,D$ to A D, *plus* the pressure due to the part $c\,D'$, if suspended at C; and the two pressures

[12] The planes must be such as to preserve the equilibrium of the truss. If the angle $u\,A\,m$ were greater than $x\,A\,m$, say $= u'\,A\,m$, the beam A C would slide up in the direction $A\,u'$, unless prevented by friction.

[13] This is true as regards a truss; but if a single beam be placed aslope and supported at its two ends, the directions of the pressures at those points will be perpendicular to the planes of support. —Tredgold's 'Carpentry,' Arts. 33, 34, 35, 42.

[14] Hutton's 'Mathematics,' vol. ii. Prop. 31, Art. 169.

will be to each other inversely as their distances from the line V D′, which will coincide with the line W D′.[15]

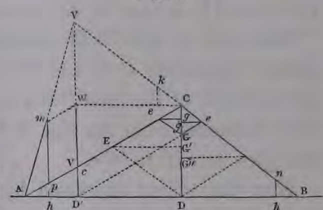
The only vertical pressure at B is $C g'$, being that caused by the portion of weight acting at C, which, by the principle of the lever, as shown above, is C G; and by similar triangles, $C g' : C G'' :: (C G \text{ or}) \; c D' : C D$, or as $A D' : A D$. In like manner, $C g$ expresses the vertical pressure at A caused by C G or $c D'$, to which must be added the weight $W c$, which rests solely on A; and by similar triangles, $(W c \text{ or}) \; G D : C D :: D' D : A D$.

Lay off $h A$, $h B$, each $= g e$, then $p h$ is $= C g$ and $n h = C g'$. To $p h$ add $m p = W c$, the portion of the weight directly sustained at A. Draw the lines $m A$ and $n B$, which will express the resulting amount and direction of the strains at A and B, and prolong these lines to V, from which drop a vertical line $V v$.

Now the line $V v D'$ will coincide with the line $W D'$; for by similar triangles,

$$k e : e C :: V v : v C,$$
$$\text{also } m p : (A p \text{ or}) \; e C :: V v : A v;$$
$$\text{whence } k e : m p :: A v : v C;$$
$$\text{but } (c D' \text{ or } C G \text{ or}) \; k e : (W c \text{ or}) \; m p :: A c : c C.$$

Fig. 9.



Therefore $A v : v C :: A c : c C$, which is to say that the points v and c coincide, and consequently the lines $V D'$ and $W D'$, and V is the point of action, or of meeting of the three forces $W D'$, $A m$, and $B n$. Moreover, as proved in Art. 10, $m h : n h :: B D' : D' A$.

22. If a horizontal force act against one side A C of a truss A C B, fig. 10, the vertical strains at A and B will be equal and opposite, and such as are due to the proportion of the force which acts at C.

Let $F E = A D$ represent the force which, by the principle of the lever, will produce effects at the points C and A in inverse proportion to the distance of the force from those points, or by similar triangles, as $F c$ to $c E$. Lay off these lengths at $f C$ and $A p$, and resolve the former into the forces $k C$, $k' C$, in directions of the two beams C B and A C.

Now the force $A p$ causes no vertical strain, and the force $f C$ alone exerts

[15] In other words, the weight divides itself between the fulcra A and B as it would do if resting on the beam A B at D′.

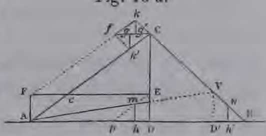
two equal and opposite strains, $k' g$ and $k g'$, of which the former tends to lift the truss at A, and the latter presses on it at B.

23. Also the horizontal thrust at B will be that due to the portion of the force which acts on C, and the horizontal push at A will be the portion of the force which acts directly on A, *plus* that due to the portion acting at C; and both these thrusts will act in one direction from A to B, and they will be to each other directly as their distances from the vertical line V D′ drawn from the intersection of the lines of strain on A and B.

For the force k C exerts its horizontal thrust h' B (made equal to g' C) at B, and k' C does likewise at A, by tension of the beam C A. Add therefore $p\,h$ (= the strain $f g'$) to A p, making the whole strain at A = A h, and it is evident that both the forces A h and h' B act in one direction from A to B, their sum being the whole force F E.

Lay off the vertical strain $k' g$ or $k g'$ at $h\,m$ and at $n\,h'$, and draw the straight line A V through m; then A m and n B express the amount and direction of the combined strains on A and B, and V will be their point of meeting, from which drop the vertical line V D′. Then by similar triangles,

Fig. 10 *a*.



$$A h : (m h \text{ or}) \; n h' :: A D' : V D',$$
$$\text{also } h' B : n h' :: D' B : V D';$$
$$\text{whence } A h : h' B :: A D' : D' B.$$

24. And no change in the lengths of the beams, or in the slope of that beam against which the force F E directly acts, will alter the strains while the angle formed by the opposite beam B C with B A remains unchanged.

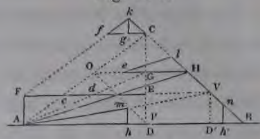
For suppose the beam A C to be removed, a beam being substituted for it in the position A H; and let B C be shortened to B H. Draw O H parallel to A B, cutting C D at G. Now a line drawn from A to G will divide F E into two parts, F d, d E, proportionate to its distances from the fulcra A and H; and laying off the former at e H, and drawing $e\,l$ parallel to A H, we have l H to express the direct pressure on H B produced by the force e H or F d.

By similar triangles (see fig. 10 *b*),

$$(F c \text{ or}) \; f C : (A D \text{ or}) \; F E :: A c : A C,$$
$$\text{also } (F d \text{ or}) \; e H : \quad F E :: A c : A O;$$
$$\text{therefore } f C : A O :: e H : A C.$$

or by similar triangles, (O P being drawn parallel to C B,) fC : A P :: eH : A B, which, by substituting other similar sides of the two pairs of similar triangles, fkC, A O P, and elH, A H B, becomes kC : O P :: lH : H B; and H B being equal to O P, lH is also equal to kC, and, as a necessary consequence, all the corresponding resultant strains both at A and B in the two trusses A C B and A H B must be the same.

Fig. 10 b.



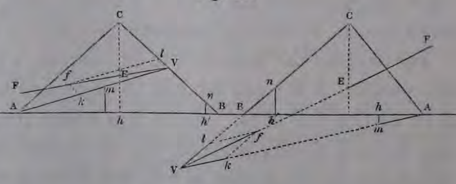
25. The point of meeting V of the directions of the ultimate strains Am and nB will also be cut by prolonging the line of the causal force F E, and will be its point of action; for by similar triangles,

fC : (kg' or) mh :: A B : C D,
also A D : mh :: A B : V D′;
whence fC : V D′ :: A D : C D.

Again, by similar triangles, (Fc or) fC : F A :: A D : C D; therefore F A must be equal to V D′, and the prolongation of the line F E must pass through V. It is seen also in figures 9 and 10, that where a force either vertical or horizontal acts on one beam A C of a simple truss A C B, the direction of the strain, and consequent re-action in the opposite beam B C, is in the axis of its length.

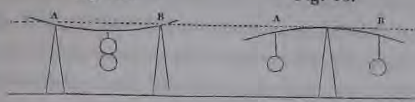
26. And the effect of a force F E, fig. 11, acting in any direction between the vertical and horizontal, on one side A C of a simple truss A C B, may be found by the same process, and its ultimate strains will always be such as though it were concentrated at V; and as that point is found by prolonging the line of direction of the force till it meets the line of axis of the opposite beam B C (Art. 25), it affords a ready method of determining those strains kV and lV, equal to Am and nB respectively, fV being laid off equal to F E.

Fig. 11.



27. Let A B, A B, figs. 12, 13, be two beams of equal dimensions, the one supported at the ends, and loaded at the centre with a weight equal to 2 W, the other supported at the centre, and loaded at each end with a weight equal

Fig. 12. Fig. 13.



to W, the distances between the props and the weights being in both instances the same; then will the curve, the deflection, and the tension of the beam, be the same in both figures.

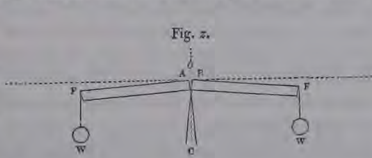
For the weights are the same, and the levers, or lengths between the fulcrum and weight, are the same in both figures; therefore the curves, the deflections,[16] and the tensions of the two beams, will also be the same.[17]

[16] The deflections being supposed small, the slight contraction in the length of the lever, fig. 13, from that cause would be of no appreciable amount. With this trifling difference, fig. 13 is evidently fig. 12 reversed.

[17] Barlow's 'Essay on the Strength and Stress of Timber,' edition of 1826, Art. 101. This is a suitable place to remark, that in Art. 91 of Mr. Barlow's Essay, a confusion, apparently, of the terms extension (elongation) and tension (the strain causing elongation) has led to an erroneous cause being assigned for certain differences of deflection observed in a beam fixed at one end and a beam supported at the centre. The comparison is between a beam fixed by one end in the wall, and bearing at the other end a breaking weight; and another beam of the same scantling, but of twice the length, supported at the centre, and bearing at each end a weight equal to that on the short beam; and it is correctly stated that the tension in both cases is the same. It is then argued that the deflection in the one case will be the double of that in the other; "for," it is added, "the extension of the fibres being equal by the supposition." But no such deduction can be drawn from the supposition, which was that the tension in both beams was the same, while the extension, it may be shown, would be as the lengths of the beams; and if after making this correction the reasoning in the Essay were to be resumed, it would lead to the conclusion that theoretically the deflections of the two beams should be equal.

The view here taken of the subject will be clearer with the assistance of the figure in Mr. Barlow's Essay (Plate I. fig. 8).

Fig. z.



Let F F be a beam supported in the centre by a prop C, and W, W, two equal weights, supported by the two ends. The tension of the upper fibres (compared by Mr. Barlow to a line passing over a pulley) will be that of one weight W, acting by the lever *o* F. Also, let A B represent the extension of the fibres caused by the strain.

Now let us suppose the beam to be sawed through across the middle, but at the same the two newly made extremities at that section *o* C, so firmly clasped as to keep them in close contact at the point *o*, and prevent the possibility of the upper fibres drawing out. It is plain that there are now two beams, each acted on by W with the lever *o* F, but that the extension of each is only half the extension of the double beam, while the deflection before and after the sawing is the same.

Or to take the simile of a line and pulley, as given in Mr. Barlow's Essay, Art. 91, in these

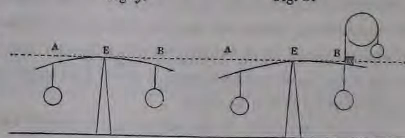
28. But if the weights be spread uniformly throughout the beams, the curves will no longer be the same. For on this supposition in the beam

words,—"A line passing over a pulley, and loaded at each end with an equal weight, has the same tension as a single fixed line loaded with only one of those weights." This is indisputable; but assuming the former line to have twice the length of the latter (as the beam F F has twice the length of F o), it will also have twice its extension. For suppose the pulley to be made immoveable, and the line nailed to its vertex. The weights and line, after this operation, remain in *statu quô*. The tension on every part of the line is, as before, that of one weight, while the extension of the whole line is, also as before, twice that of the single fixed line loaded with one weight.

In other words, weight and the tension caused by it remaining constant, extension will be as length; and, this law being admitted, it follows that the deflection of a beam fixed at one end and loaded at the other, ought, by the train of reasoning pursued in the Essay, Art. 91, to be no greater than the deflection of a beam of the same scantling but of twice the length, supported at both ends and loaded at the middle with a double weight. Nevertheless this conclusion, however satisfactorily demonstrated, would be far from the truth, for this reason, that to make it practically correct, the shorter beam must be not merely fixed, but its end so firmly grasped at A or B, as to be immoveable there in respect to all its fibres,—a condition never fulfilled, and the erroneous assumption of which could not but lead to inaccurate results. The fact, as known from experiment, is, that the deflection of the shorter beam will be about twice the deflection of the longer; and the following attempts at an explanation of the cause are offered to the consideration of the reader.

Let A B, fig. y, represent a beam supported at the centre and loaded at the ends with equal weights, causing deflections at A and B, each $= d$, and let figure x represent the same beam with one end B raised to a level with the fulcrum E, and there retained. The end A will have dropped as much as B has risen, and the deflection there has consequently become $= 2\,d$. Now figure x exhibits to us the case of a beam A E equal in length to the half of the beam A B in fig. y, and loaded with half its weight, but having twice its deflection at A, while the flexure at E, the extension of fibre, and the length through which the extension acts, are the same in both figures. Now if we suppose the portion of the beam from E to B in fig. x, to be built up, and the weight at B removed, we have the beam fixed at one end, as described in the Essay, Art. 91, with this slight difference,—that in the latter, the beam from E to B being fixed before loading is straight, the abruptness of the flexure at E being thereby increased, but the resistance of the upper fibres from E to B at the same time diminished. The effect of this difference is probably small, and we should therefore be led to expect, without the aid of experiment, that the shorter beam, fixed at one end, would have nearly the double deflection which is exhibited in figure x at A.

Fig. y. Fig. x.



The double deflection of the shorter beam, fixed at one end, may also be accounted for on the ground that it demands no greater flexure at the fulcrum than the single deflection does in the double beam. For conceive the curve to be made up of a number of short straight lines, and that supported at both ends, the centre is pressed by a small portion only of the weight, and will be scarcely bent; while the extremities will divide the whole weight. On the other hand, in the beam supported at the centre, the flexure will be greatest there, while the extremities will be nearly straight; for though the weights are equally spread, the resistance of the fulcrum is at one point only, and is that of a counterweight = 2 W, supporting the centre. And it results from experiment that the deflections, as well as the curves, are altered, and that their proportions are as follow, the beams and weights remaining constant. (Barlow's Essay.)

1st. In a beam loaded uniformly throughout, and supported at the centre, Deflection = 3.
2nd. In a ditto ditto ditto, and supported at the ends, Deflection = 5.
3rd. In a beam loaded distinctly at the centre or ends, as in figs. 12, 13, Deflection = 8.

And the weights being as the deflections (Barlow's Essay), must be inversely as these numbers to produce equal deflections in beams loaded as above described.

29. Let C D, fig. 14, represent a beam of the same scantling as A B in figures 12 and 13, and let the distances between the props and weights be the same, and W the same weight as before. Here the weight at the centre has not only to produce the deflection there, but moreover the deflections at F and F by counterpoising the weights suspended from C and D, each = W; and if the weight at E be made = 4W, we shall have the deflections at E and F and F all equal, and the same[18] as in figures 12 and 13 (Barlow's Essay, Art. 107).

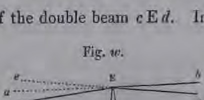
For we require at the centre E, $2w$ to counterbalance the weights at C and D, as in fig. 13, and $2w$ remain available to produce the deflection at E, as in fig. 12.

And if half of the weight were removed from E, that point should be

---

two of these meet at the fulcrum E, representing there the curvature of the double beam c E d. In this case the curvature of the shorter beam, fixed at one end, granting it only the same deflection as the double beam, would be expressed by the meeting of one of these lines with a horizontal line, or c E b. Now the angles measuring these curvatures are e E c and a E c, the latter being half only of the former; and to make the curvatures at E equal, the deflection of the shorter beam must be doubled.

Fig. w.



[18] Or nearly the same. It is probable that the extent of the deflections in fig. 14 might be slightly affected by their combination.

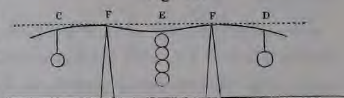
undeflected, and the deflections from the horizontal at C and at D should be doubled; for the weight remaining at E = 2 w, would exactly counterpoise the weights at C and D, leaving the part F F free from all strain.

Moreover, the removal of all weight from the centre should cause E to rise above the straight line F F as much as it was depressed below it by the whole weight. For the point E would be raised by w acting with lever C F on one side, and by w acting with lever D F on the other, which is the same in effect as though the 2 w were united above the centre to act over a pulley on E. Also the deflections at C and D would in this case be trebled, but throughout all these changes the flexures at the fulcra would remain unaltered.

30. But the weights, if uniformly distributed throughout their respective divisions, must be otherwise proportioned in order to secure equal deflections. For while the weights on C F, F D require, as before, equal counterweights on F E, E F, smaller weights will suffice to produce an equivalent deflection at E (Art. 28).[19]

And the weight being distributed equally throughout the whole beam, there would be no deflection at E, for the parts C F, F D are in such case a precise counterpoise to F E, E F; and the deflections at C and D would be $\frac{3}{5}$ of the deflections due to the same weight divided between the central and extreme points of the beam, in the proportion of half to the centre and half to the two ends.[20]

Fig. 14.



31. Suppose now in fig. 15, the levers as before, as also the weight w, and that 3 w and w are respectively suspended from the points E and D. Here the weight at E has to produce the deflection at E, and, in opposition to the weight at D, the deflection at F, but none at the opposite prop. In this instance, therefore, the weight 3 w should cause a deflection equal to that in the three preceding figures; for one portion w would be absorbed in overcoming the resistance to flexure at F, and 2 w would remain to produce the

[19] In the proportion of 3 to 5, if we accept for our guidance experiments separately made on fulcral and medial deflections (Art. 28). It is as yet, however, undetermined whether combining the deflections does not alter the ratio of the weights causing them, as it certainly alters the forms of the curves.

[20] They would be $\frac{3}{8}$ in a beam resting on one prop, as in fig. 13; but here the parts C F, D F must obviously have the deflection due to the weight pervading F F, which they cancel.

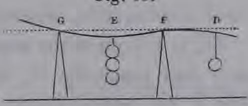
strain and deflection at E, which strain bears equally on the two props. Consequently the prop G in this figure carries only one-third of the weight at E, while the prop F supports the remaining two-thirds, besides the weight at D.

But if we increase the weight at E to $4w$, a change will be effected in the distribution of its pressure, the additional weight w tending entirely to augment the deflection at E. For the resistance to flexure at F was caused by the weight w on the opposite side of the fulcrum, which has already been counterbalanced by an assigned equal weight, namely, one-third of the weight first suspended at E. The curvature at F therefore cannot be augmented by additional weights at E while the weight at D remains constant, their only effect being a further depression of the centre E and an equal rise of the end D. The point E then being loaded with $4w$, $\frac{3}{8}$ths of that weight will press on the prop G and $\frac{5}{8}$ths on the prop F.

And in like manner, any further additional weight laid on at E will have no resistance to overcome at F, but will exert its full force in increasing the deflection at E, and will consequently press equally on the two fulcra.

And if we reduce the weight at E to less than $3w$, the same law will still govern the distribution of the pressure and the deflections. For suppose the whole weight to be removed from E, there would then be a tendency to rise at that point equivalent to the force of the weight w acting at D with the lever D F, and a weight $= w$, imposed at E, would just counterpoise this tendency, and leave the fulcrum G free from pressure. Now whatever weight in excess of w we may impose at E, would evidently begin to press on G as well as on F, and being at equal distances from those points, its pressure would be the same on both; or, if elsewhere placed, it would press on the fulcra in inverse proportion to its distance from either of them.

Fig. 15.

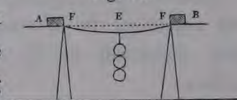


32. If the weights $4w$ were uniformly spread over the whole beam from G to D, the prop G would bear w, and the prop F, $3w$. For the parts E F and F D $= \frac{8}{3}w$, would rest on F in equilibrio, leaving the weight from G to E $= \frac{4}{3}w$ disengaged, which, pressing on G and F in the ratio of 3 to 1, would add $\frac{w}{3}$ to the pressure at F, making a total there of $3w$. Or we may conceive

$F D = \frac{4}{3} w$ as balancing half its weight spread from G to F,[21] and there will remain $2w$ spread from G to F, acting equally on the two props, and causing the deflection at E, which deflection was on the former supposition produced by $\frac{4}{3} w$ distributed through G E. The pressure on G, according to either supposition, is $= w$. Hence we arrive at the conclusion, in respect to the demi-interval G E in this figure, that a weight distributed over it should cause the same deflection as $\frac{3}{2}$ of the same weight distributed over the whole interval G F.

33. Let A B, fig. 16, represent a beam of the same scantling, and supported by fulcra at the same interval as in figures 12, 13, and let the ends of the beam be prevented from rising by two horizontal checks A F, B F; then will the weight required on the centre of this beam to produce a certain deflection, be to the weight causing the same deflection of the beams in figures 12, 13, in the ratio of 3 to 2.

Fig. 16.



For the flexure at each of the fulcra in this figure being a half only of the flexure at the fulcrum in fig. 13, the resistance is also only half, or $\frac{w}{2}$, because the flexures are proportional to the weights causing them.[22] We require therefore a weight $= w$ to produce the two deflections at F, F and $2w$ for the deflection at E, as in fig. 12, making a total of $3w$, which is to the weight employed in figs. 12, 13, as 3 to 2,[23] a result confirmed by experiment.[24]

34. If a beam of the same scantling as in the preceding figures be extended over three props, fig. 17, their distances and the weight w remaining as before, and if the central points between the props be each loaded with $3w$, the deflections will be the same as in figures 12, 13, and the middle prop E will bear four times the weight borne by either of the side props F, F′.

For in this case there are three deflections to be produced, at A, at E, and

[21] This supposition is inadmissible when two opposite strains meet and intercept each other's action. Let a weight be uniformly distributed over the beam C D, fig. 14, and let us suppose, as in this instance, that F D balances only half of its weight spread over F F, and that C F does likewise. On that supposition they would both together balance only half the weight of F F, whereas they ought to be an exact equipoise for the weight distributed over that space, the parts C F and F D balancing F E and E F respectively.

[22] Barlow's Essay.

[23] And to the weight employed in fig. 14 as 3 to 4; because the flexures to be produced at the fulcra in that figure are double the flexures at the fulcra in fig. 16.

[24] Barlow's Essay, Art. 107.

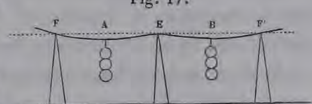
at B, and all these deflections must be equal, because the levers and the weights between the props which produce them are equal. Each deflection therefore will be that due to $2\,w$, or the same as in figures 12 and 13.[25]

And the weights producing the deflection at E will press solely on that prop, which also bears half of the weights causing the deflections at A and B, $4\,w$ in all; while each of the outer fulcra F, F′ will carry only w, being half of the weight making the deflection at A or B.[26]

An additional weight w imposed now at A would not confine its effect to the space F E, but would modify all the deflections and pressures. For the deflection at E must necessarily be a mean between those at A and B, and would therefore occupy one-third of the whole weight, or $\frac{7}{3}w$, leaving $(4\,w - \frac{7}{6}w =)\ \frac{17}{6}\,w$ available for the deflection at A, and $(3\,w - \frac{7}{6}w =)\ \frac{11}{6}\,w$ for the deflection at B. And the weights on F, E, F′ respectively would be $\frac{17}{12}w$, $\frac{56}{12}w$, and $\frac{11}{12}w$.

35. Let the weights in figure 17 be considered now as uniformly distributed throughout the whole beam, and let a portion x of this weight, also equally diffused from F to F′, be conceived to cause the deflection at E, in effecting which it is assumed to be equivalent to $2\,x$ spread from A to B, which would act with levers of only half the length. The weights required to cause compensating deflections at A and B, acting also with the half levers, should be each $\frac{3}{5}$ths of this latter weight (Art. 28), or $\frac{6}{5}x$. Hence the equation $x + \frac{12}{5}x = 6\,w$, giving $x = \frac{30}{17}w$. Also, the fulcrum E would sustain $x + \frac{6}{5}x = \frac{66}{17}\,w$ and F, F′ each $\frac{3}{5}x = \frac{18}{17}w$.

Fig. 17.



Now we have assumed the deflection at E to be that due to $2\,x$, spread through A B, for which, if the value just found, $\frac{60}{17}w$, be substituted, we observe that it is more than A B, the weight of which is only $3\,w$, can contain. The

[25] Or nearly so. See note to Art. 29.

[26] If the beam be inflexible by the weights imposed, the central prop will bear only twice the pressure borne by each of the side props; but if the smallest deflection take place, the conclusion above stated becomes unavoidable.

assumption, therefore, that the fulcral deflection at E can be produced by any weight within the capacity of A B not being in this instance tenable, we must suppose it produced partly by a weight spread through A B, and partly by a weight diffused through the whole beam F F′. The former weight can be neither more nor less than the sum of the weights supposed to occupy F A and F′ B, and to produce the medial deflections at A and B. Hence, calling either of the latter weights y, its equivalent, when spread over F E or F′ E, would be $\frac{3}{2} y$ (Art. 32); and we have the equation $\frac{3}{2} y = \frac{3}{5} \times \left\{2 y + 2 \, (6 w - 4 y)\right\}$, giving $y = \frac{24}{17} w$, and the pressure on E will be $= 2 y + \frac{2 y}{4} + 6 w - 4 y = \frac{66}{17} w$, and on F, F′ each $= \frac{3}{4} y = \frac{18}{17} w$, which are the same as those before found.

36. The beam shown in figures 12 and 13 being further extended, so as to cover four or more fulcra, the levers and the weight w being as before, then, to produce the same deflections as in those figures, $3 w$ will be required for each of the outer intervals and $4 w$ for each of the central intervals,[27] which latter will be similarly loaded and deflected with the interval F F in figure 14. And the two outer props will each sustain a weight $= w$, while each of the intervening props will carry $4 w$.

37. Let figure 18 represent a beam covering five props, and suppose the whole weight $= w$, instead of being adjusted for the production of equal deflections, to be divided into four equal portions, and suspended at the points A, B, B, A, and let these letters, with E, E, D at the fulcra, express the weights causing deflections at their respective points. We then have the following equations to find the pressures. $2 A + 2 B + 2 E + D = w$, and $A + \frac{E}{2} = \frac{w}{4}$, or $4 A + 2 E = w$; also $\frac{A + B}{2} = E$, and $\frac{B + B}{2} = D$, or $B = D$. Whence are found $A = \frac{3}{17} w$, $B = D = \frac{2}{17} w$, and $E = \frac{5}{34} w$, and the pressures on the props are—

On F, F, each $\frac{A}{2} = \cdot 0882353 \, w$, which $\times \, 2 = \cdot 1764706 \, w$.

On E, E, each $\frac{A}{2} + E + \frac{B}{2}$, or $2 E = \cdot 29411765 \, w$, which $\times \, 2 = \cdot 5882353 \, w$.

And on D, $\frac{B}{2} + D + \frac{B}{2}$, or $2 D$ . . . . $= \cdot 2352941 \, w$.

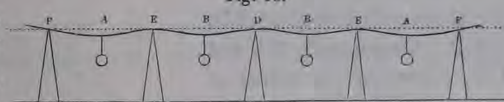
Total $= 1 \cdot 0000000 \, w$.

[27] Hence the great advantage of length in purlins, rafters, flooring planks, &c., which should be made to extend over as many intervals as the timber will admit of; and this advantage is independent of that gained by nailing, nor does the uniform distribution of weight diminish it.

38. Now suppose the same weight to pervade uniformly the whole length of beam from F to F, and that the letters A, B, D, E express, as before, the weights causing deflection at those points. The ratio of the weights required to produce the medial and fulcral deflections, when combined as in this figure, not being ascertained, we must assume it to be the same as the ratio for the deflections separately produced, or 3 to 5 (Art. 28).[28] This is the ratio of weights uniformly distributed over the whole interval; but A and B are not supposed to be so, as will be presently explained. Let therefore A′ and B′ represent the weights which equally spread throughout F E, and E D would be equivalent to A and B in causing deflection. We shall thus have the following four equations: $2\,A + 2\,B + 2\,E + D = w$; $A + \frac{E}{2} = \frac{w}{4}$; $\frac{A' + B'}{2} = \frac{3}{5}E$, and $\frac{B' + B'}{2} = \frac{3}{5}D$.

These two last equations must be reduced to their values, in terms of A and B, in the following manner. The weights causing the fulcral deflections are supposed (for the reason given in note to Art. 32) to pervade only the nearer half of each adjoining interval. Thus the weight E is supposed equally distributed from A to B, and the weight D from B to B.

Fig. 18.



As a moiety A E of the division F E is thus occupied to the amount of half the fulcral weight, or $\frac{E}{2}$, a certain portion of A must occupy the vacant moiety A F to the same extent, and the surplus of A must be spread equally over the whole division F E; the first portion exerting a power of medial deflection at A equal to that which three halves of its weight uniformly pervading F E would possess (Art. 32). That is to say, $\frac{E}{2} \times \frac{3}{2} + A - \frac{E}{2}$, or $A + \frac{E}{4} = A'$, and in like manner $\left(\frac{E}{2} - \frac{D}{2}\right) \times \frac{3}{2} + B - \left(\frac{E}{2} - \frac{D}{2}\right)$, or $B + \frac{E}{4} - \frac{D}{4} = B'$.

[28] As the discrepancy between the fulcral and medial deflections of the same beam under the same uniformly diffused weight (determined by experiment) is attributable to the difference of the curves formed in the two cases (Art. 28), and as when fulcral and medial deflections are combined, the forms of both curves are, doubtless, modified by their mutual incorporation,—it seems not improbable that the ratio of the deflections may also be thereby changed.

Substituting these values in the third and fourth equations, they become $A + B = \frac{7}{10}E + \frac{D}{4}$ and $B = \frac{17}{20}D - \frac{E}{4}$, and the values of the deflecting weights come out $A = \frac{151}{1124}w$, $B = \frac{71}{1124}w$, $E = \frac{260}{1124}w$, $D = \frac{160}{1124}w$, also $A' = \frac{216}{1124}w$, and $B' = \frac{96}{1124}w$; whence the pressures on the fulcra are found,

$$\text{On F, F, each} = \frac{A'}{2}, \text{ which} \times 2 = \frac{216}{1124}w = \cdot 1921708\,w.$$

$$\text{On E, E, each} = A - \frac{A'}{2} + E + B - \frac{B'}{2}, \text{ which} \times 2 = \frac{652}{1124}w = \cdot 5800712\,w.$$

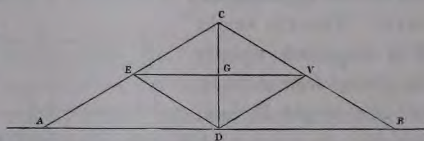
$$\text{On D,} = B' + D = \frac{256}{1124}w = \cdot 2277580\,w.$$

$$\text{Total } \overline{1 \cdot 0000000\,w.}$$ [29]

39. Let ACB, fig. 19, represent the cross section of a roof of which the tie-beam AB is horizontal, and the angles at A and B are each $= 30°$, and let the vertical line CD express the value of a weight suspended from C; then,

As radius : AD : : tangent $<$ CAD : CD $= \cdot 57735$ AD, and AD is $= \frac{CD}{\cdot 57735} = 1 \cdot 732$ CD.

Fig. 19 *a*.



Completing the parallelogram CEDV, we have in this case two equiangular triangles, CED, CVD. Consequently CE and CV, expressing the values of the pressures in direction of the lengths of the principal rafters (Art. 3), are each $=$ CD, and AC $= 2$ CD, or $1 \cdot 1547$ AD.[30] Also the opposite and equal horizontal strains GE, GV are each $= \frac{AD}{2}$ or $\cdot 866$ CD, and the vertical strain on either side $= \frac{CD}{2}$.

[29] If the fulcral weights be viewed as each extending over two entire intervals and acting with double levers, the third and fourth equations above given become $\frac{A + B}{2} = \frac{3}{5} \times 2E$, and $\frac{B + B}{2} = \frac{3}{5} \times 2D$, and the resulting pressures on the fulcra are—

$$\text{On F, F, each} = \frac{A}{2}, \text{ which} \times 2 = \cdot 1844485\,w.$$

$$\text{On E, E, each} = \frac{A}{2} + E + \frac{B}{2}, \text{ which} \times 2 = \cdot 5768535\,w.$$

$$\text{And on D} = B + D = \cdot 2386980\,w.$$

$$\text{Total} = \overline{1 \cdot 0000000\,w.}$$

Which differ somewhat from those above found.

[30] If the angle A be made 33°, AC is $= 1 \cdot 836$ CD, and AD $= 1 \cdot 5398$ CD.

And if E V represent a straining beam, the stress of a weight E I placed at E will be double the stress of the same weight at C (Art. 8); for its strain in the direction of the length of the principal will be expressed by $EA = 2EI$, and its horizontal strain will be I A, or $EG = 1{\cdot}732\ EI$.

40. Let F E, drawn parallel to the horizon, express the strength of wind blowing against the face A C of the roof, and draw F H parallel to A E. The effective pressure[31] of the wind on the surface of the roof and on the battens, rafters, and purlins supporting it at right angles, will be H E made perpendicular to A C, and which, the triangles E H F and C G E being similar, is $= \frac{FE}{2}$.

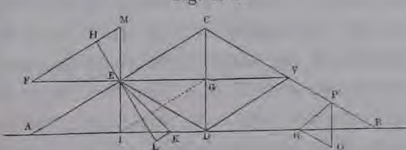
E K representing a strut inclined from the horizon at an angle of 44° 48′, and H E being prolonged to L, where it is met by the line K L parallel to E A, then, as sine $< EKL : EL ::$ sine $< KEL : KL = {\cdot}2717\ EL$, the direct strain caused by the pressure E L on the principal E A, and as sine $< EKL : EL ::$ sine $< ELK : EK = 1{\cdot}03625\ EL$, the strain on the strut E K. If the inclination of the strut be reduced to 38° 57′, L K becomes $= {\cdot}38486\ EL$ and $EK = 1{\cdot}0715\ EL$.

41. If M E represent the weight on a purlin placed at E, the stresses in directions of its depth and of its width will be H E and M H. By similar triangles,

$$CE : GE :: ME : HE = {\cdot}866\ ME,$$

$$\text{and } CE : CG :: ME : MH = \frac{ME}{2}.$$

Fig. 19 *b*.



The stress of a weight P Q, acting on any strut P R, will be expressed by P R if R Q be drawn parallel to P B, and the stress on the principal P B will be R Q. As sine $< PRQ : PQ ::$ sine $< PQR : PR$ and $::$ sine $< RPQ : RQ$, giving $PR = {\cdot}8974\ PQ$ and $RQ = {\cdot}7353\ PQ$ when the angle P R B is 44° 48′, and $PR = {\cdot}92795\ PQ$, with $RQ = {\cdot}8333\ PQ$, when that angle is 38° 57′.

The tension on a vertical post W R caused by the push P R of a strut will be expressed by S R, and the horizontal thrust by P S.

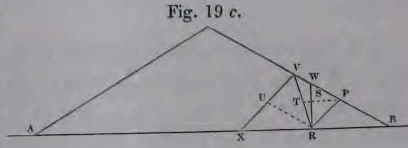
[31] 'Hutton's Mathematics,' vol. ii. Art. 51, Prop. 9, Cor. 1 and 2.

As secant $<$ S R P : P R :: radius : S R = ·7046 P R,
and as secant $<$ S P R : P R :: radius : P S = ·7096 P R,

the angle P R B being supposed = 44° 48′.

The tension exerted on a rod V R by the push P R of a strut is expressed by T R, and the horizontal thrust at R by P T, and by proportion of sines of angles to their opposite sides, the angle P R B being supposed = 38° 57′ and angle V R X = 74° 15′, we obtain T R = ·6532 P R and P T = ·955 P R. Also, if S R express a weight acting on the rod R V, T R = 1·039, S R will be the tension of the rod, and S T = ·281, S R the push at R.

Fig. 19 *c*.



Lastly, if we take V R to express the stress of this rod on a triangle X V B, U R drawn parallel to V B will express the strain on that principal, and V U the strain on the strut V X, and the angle V X B being supposed = 44° 48′, we obtain by ratio of sines o. angles to their opposite sides, U R = ·9059 V R and V U = ·7231 V R.

42. Fig. 20 represents a truss of 40 feet span, supporting, with other trusses placed at intervals of 10 feet, a roof which slopes 30° from the horizon, and has an extreme span from eave to eave of 50 feet. The tie-beam is supported at equal intervals of 8 feet, and the purlins and wall-plate are also separated by equal distances of 6·35 feet. The struts, rods, and queen-posts are so disposed as in a great measure to neutralize pressure on the principal rafters, except in direction of their length, and the common rafters are supposed to extend in one length from ridge to eave, and to be 15 inches apart. The battens are each 2″ × $\frac{3}{8}$″, and their edges 2 inches apart, covered by a double bamboo mat; the eaves single-tiled, the lower row being laid in chunam, the rest of the roof double-tiled, and the ridge of chunam.[32]

43. Calculation of the weight of the roof.

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[32] Excepting the truss, in which there are some peculiarities: this is a description of an ordinary Bombay roof, selected for the convenience of readily ascertaining the weights.

Weight of 1 square foot double-tiled, exclusive of purlins and truss.

22 tiles, each 10″ long, $3\frac{1}{4}$″ mean diameter, and weighing, when wet, 20 oz.[33]	= 27·5 lbs.
1 square foot of doubled bamboo mat, weighing 7 oz.	= 0·4375 ,,
$3'' \times 2'' \times \frac{3}{8}'' = 27$ cubic inches teak battens, of specific gravity 745[34] = 11·64 oz.	= 0·7275 ,,
$\frac{4'}{5} \times 3''$ diameter = 67·85856 cubic inches teak rafter, of do. = 29·256 oz.	= 1·8285 ,,
$2\frac{2}{5}$ batten nails, length $1\frac{3}{4}$ inch, 100 per lb.	= 0·0240 ,,
Total . . .	= 30·5175 ,,

And the weight of 1 square foot, single-tiled, is less than the above by the weight of half the number of tiles = (30·5175 lbs. − 13·75 lbs. =) 16·7675 lbs.

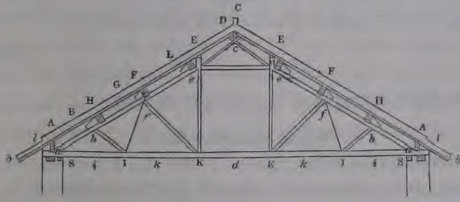
Weight of one chunam eave.

10 running feet of chunamed eave, tiles exclusive, at 9 lbs. per foot .		= 90 lbs.
1 teak eave board, $10' \times 4'' \times \frac{3}{4}''$	= 360 cubic inches.	
Deduct for the displaced batten, $10' \times 2'' \times \frac{3}{8}''$ =	90 ,,	
	270 cubic inches .	= 7·275 ,,
	Total . . .	= 97·275 ,,

Weight of chunam ridge.

10 running feet chunam ridge, including ridge-tiles, at 28 lbs. per foot . = 280 lbs.

Fig. 20.



[33] These tiles make a very heavy covering, as they lie four deep; namely, two with the edges up and two with the edges down. The section of a tile is semicircular, but it is smaller at one end than the other, so as to fit into the subjoining tile. It is unglazed, and very porous.

[34] A cube of 6 inches, cut from a log of small-sized Calicut teak timber, freshly imported to Bombay, weighed exactly 7 lbs. After 18 months' exposure in an open room it had shrunk $\frac{1}{16}$th inch in each of its lateral dimensions, but not sensibly in its length, and it weighed 5 lbs. $10\frac{1}{2}$ oz.; after which its weight remained unaltered until it was slightly affected by the following rainy season. This weight and size give a specific gravity of 739·2, which so nearly agrees with that given by Professor Barlow (Essay, Art. 143, Table), that I have adopted the latter.

Weight of ridge-pole.

1 teak ridge-pole, $10' \times 2\frac{1}{2}'' \times 7\frac{1}{2}'' = 2250$ cubic inches	=	60·6283 lbs.
16 rafter nails, length 6 inches, 8 per lb.[35]	=	2·0000 ,,
1 ridge-nail, length 9 inches, 4 per lb.	=	0·2500 ,,
Total	=	62·8783 ,,

Weight of a purlin and block.

1 teak purlin, $10' \times 4\frac{1}{4}'' \times 6\frac{3}{4}'' = 3442{\cdot}5$ cubic inches	=	92·7612 lbs.
1 teak block, $1' \times 5'' \times 3\frac{1}{2}'' = 210$ cubic inches	=	5·6586 ,,
8 rafter nails, length 6 inches, 8 per lb.	=	1·0000 ,,
1 purlin nail and 2 block nails, length 9 inches, 4 per lb.	=	0·7500 ,,
Total	=	100·1698 ,,

Weight of the truss.

1 teak tie-beam, $45' \times 5'' \times 5'' = 13500$ cubic inches	=	363·7696 lbs.
2 principal rafters (each $19' \times 5'' \times 6{\cdot}01''$) = 13702 cubic inches	=	369·2342 ,,
2 upper ditto (each $5' \times 3''$ diam.) = 848·232 cub. in. = 21·563 lbs. With 1 rafter nail = 0·125 ,,	=	21·6880 ,,
1 straining beam, $7'{\cdot}8 \times 5'' \times 4''{\cdot}5 = 2106$ cubic inches	=	56·7480 ,,
2 queen-posts $\left(\begin{matrix}\text{each } 9'{\cdot}6 \times 5'' \times 2''{\cdot}4 \\ \text{and } 0{\cdot}8 \times 5 \times 5\end{matrix}\right)$ = 3244·8 cub. in. = 87·4340 lbs. With 2 iron plates (each $2' \times 1'' \times \frac{1}{4}''$), iron bolt $6\frac{1}{2}'' \times \frac{5}{8}''$ diameter, and nut, altogether 9·445 cubic inches, at 4·5 oz. per cubic inch = 5·3128 ,,	=	92·7468 ,,
2 upper struts (each $8'{\cdot}25 \times 3''{\cdot}5 \times 4''$) = 2772 cubic inches	=	74·7638 ,,
2 lower struts (each $4'{\cdot}2 \times 2''{\cdot}25 \times 2''{\cdot}75$) = 623·7 cubic inches	=	16·8062 ,,
2 iron rods (each $7'{\cdot}2 \times \frac{3}{4}''$ diam. with nut) = 76·9 cubic inches	=	21·6280 ,,
Total	=	1017·3846 ,,

44. Calculation of the weight of a plastered ceiling.

Weight of a square foot.

$1' \times 1\frac{1}{2}'' \times 3\frac{1}{2}'' = 63$ cubic inches teak joist $\frac{1}{5}' \times 1\frac{1}{2}'' \times 2\frac{1}{2}'' = 9$ cub. in. batten, nailed to tie-beam $12' \times \frac{3}{8}'' \times \frac{5}{8}'' = 33{\cdot}75$ cubic inches ceiling battens } 105·75 cubic inches	=	2·8495 lbs.
$\frac{1}{5}$th joist nail, length 6 inches, 8 per lb.	=	0·0250 ,,
$\frac{1}{5}$th batten nail, length 3 inches, 30 per lb.	=	0·0066 ,,
12 ceiling nails, 240 per lb.	=	0·0500 ,,
1 square foot chunam plaster = 11 lbs. 6 oz.	=	11·3750 ,,
Total	=	14·3061 ,,

[35] A smaller nail, $4\frac{1}{2}$ inches long, is generally used to secure the rafters to the ridge-pole; but so short a nail is objectionable, as it cannot be clenched.

45. From the foregoing Articles we find the weight of roof, fig. 20, between truss and truss, to be as under, exclusive of the truss, purlins, and ridge-pole.

The span from l to $l = 45' \times 1 \cdot 1547$ for the slope (Art. 39), $\times$ 10′, the distance of the trusses, is $= 519 \cdot 615$ square feet of double tiles, which $\times$ 30·5175 tbs. weight per square foot (Art. 43), gives .	= 15857·35 tbs.
The width of the two eaves $= 5' \times 1 \cdot 1547 \times 10' = 57 \cdot 735$ square feet of single tiles, which $\times$ 16·7675 tbs. weight per square foot (Art. 43), is	= 968·07 ,,
The weight of the chunam ridge is	= 280·00 ,,
Ditto of the two chunam eaves	= 194·55 ,,
Total	= 17299·97 ,,

which weight may be thus divided:

Weight of the chunam ridge at C				=	280 tbs.
Ditto from C to E = 54·86 sq. ft.	× 30·5175 tbs.	= 1674 tbs.	which × 2	=	3348 ,,
Ditto from E to F = 63·5 ,,	× ditto	= 1938 ,,	,, × 2	=	3876 ,,
Ditto from F to H = ditto	× ditto	= 1938 ,,	,, × 2	=	3876 ,,
Ditto from H to A = ditto	× ditto	= 1938 ,,	,, × 2	=	3876 ,,
Ditto from A to l = 14·44 sq. ft.	× ditto	= 441 ,,	,, × 2	=	882 ,,
Ditto from l to b = 28·86 ,,	× 16·7675 tbs.	= 484 ,,	,, × 2	=	968 ,,
Ditto of two chunam eaves				=	194 ,,
Total				=	17300 ,,

With respect to the distribution of this weight among its several points of support, the weight of the chunam ridge rests on C only, and the strain of the projecting eave will determine the amount of pressure caused by resistance to flexure at l and A, without reference to other strains (Art. 31). The roof being supported by the wall at l, as well as by the wall-plate at A, the fulcrum on which the weight of the eave acts is the former, and it is resisted, first, by the portion of roof from l to A, and next, we shall suppose, by a certain weight spread over A B half-way from A to H (note to Art. 32). The strain of the eave is the weight of chunam = 97 tbs. $\times$ lever 2′·6 + that of the single tiles from l to b = 484 tbs. $\times$ lever 1′·443, being both together = 950·6 tbs. acting with lever 1 foot, of which the roof from l to A = 441 tbs. $\times$ ·′722 counterpoises 318·4 tbs. The remaining strain = 632·2 tbs. $\times$ lever 1′, is to be opposed by a weight uniformly pervading A B, which weight acts on the fulcrum A[36] with lever $\frac{AB}{2} = 1' \cdot 5875$, and is therefore $= \frac{632 \cdot 2 \text{ tbs.} \times 1'}{1' \cdot 5875} = 398$ tbs.

[36] Weights pervading lb and A B opposed to one another, act respectively at l and at A with certain levers, independently of the intermediate space lA, as long as both the fulcra are under pressure.

Let the letters B, G, L, D express the resistances to deflection at the medial points between the fulcra, and H, F, E the resistances to deflection at the fulcra thus marked, with the same levers. The levers from B to E being all alike, the weights on each side of H causing deflection there will be equal, as also the opposing weights at F; but the lever $\frac{\text{ED}}{2} = \frac{5' \cdot 486}{4}$ is shorter than the lever $\frac{\text{EL}}{2} = \frac{6' \cdot 35}{4}$; therefore the weights required for the fulcral deflection at E will be $\frac{3175}{5918}$E pervading E D and $\frac{2743}{5918}$E pervading E L, as the opposite strains must balance one another. The values also of all the fulcral deflections being different, the weights producing the medial deflections will occupy unequally the halves of their respective divisions (Art. 38). Let B′, G′, L′, D′ be the weights which, uniformly pervading those divisions, would produce equivalent effects. There are now the equations $\text{B} + \frac{\text{H}}{2} = (1938 \text{ lbs.} - 398 \text{ lbs.} =)$ 1540 lbs., $\text{G} + \frac{\text{H}}{2} + \frac{\text{F}}{2} = 1938 \text{ lbs.}$, $\text{L} + \frac{\text{F}}{2} + \frac{2743}{5918}\text{E} = 1938 \text{ lbs.}$, and $\text{D} + \frac{3175}{5918}\text{E} = 1674 \text{ lbs.}$ (these four equations giving $\text{B} + \text{G} + \text{L} + \text{D} + \text{E} + \text{F} + \text{H} = 7090 \text{ lbs.}$), also $\frac{\text{B}' + \text{G}'}{2} = \frac{3}{5}\text{H}$, $\frac{\text{G}' + \text{L}'}{2} = \frac{3}{5}\text{F}$ and $\frac{\text{L}' + \text{D}'}{2} = \frac{3}{5}\text{E}$. And to find the values of B′, G′, L′, D′, we have $\left(\frac{\text{H}}{2} - 398 \text{ lbs.}\right) \times \frac{3}{2} + \text{B} - \left(\frac{\text{H}}{2} - 398 \text{ lbs.}\right)$ or $\text{B} + \frac{\text{H}}{4} - 199 \text{ lbs.} = \text{B}'$, $\left(\frac{\text{H}}{2} - \frac{\text{F}}{2}\right) \times \frac{3}{2} + \text{G} - \left(\frac{\text{H}}{2} - \frac{\text{F}}{2}\right)$ or $\text{G} + \frac{\text{H}}{4} - \frac{\text{F}}{4} = \text{G}'$, $\left(\frac{2743}{5918}\text{E} - \frac{\text{F}}{2}\right) \times \frac{3}{2} + \text{L} - \left(\frac{2743}{5918}\text{E} - \frac{\text{F}}{2}\right)$ or $\text{L} + \frac{2743}{11836}\text{E} - \frac{\text{F}}{4} = \text{L}'$, and $\frac{3175}{5918}\text{E} \times \frac{3}{2} + \text{D} - \frac{3175}{5918}\text{E}$ or $\text{D} + \frac{3175}{11836}\text{E} = \text{D}'$. These values being substituted in the equations $\text{B}' + \text{G}' = \frac{6}{5}\text{H}$, &c., then become $\text{B} + \text{G} = \frac{7}{10}\text{H} + \frac{\text{F}}{4} + 199 \text{ lbs.}$, $\text{G} + \text{L} = \frac{17}{10}\text{F} - \frac{\text{H}}{4} - \frac{2743}{11836}\text{E}$, and $\text{L} + \text{D} = \frac{7}{10}\text{E} + \frac{\text{F}}{4}$, from which and the four first equations we find,

B =	832·883724 lbs.	also B′ =	987·441862 lbs.
G =	647·680616 ,,	G′ =	709·637200 ,,
L =	608·506729 ,,	L′ =	690·050257 ,,
D =	810·175258 ,,	D′ =	1242·087629 ,,
E =	1610·114905 ,,		
F =	1166·406216 ,,		
H =	1414·232552 ,,		
Total =	7090·000000 lbs.		

And the pressures on the fulcra will be,

On $C = \frac{D'}{2} + 280$ lbs. $+ \frac{D'}{2}$		$= 1522$ lbs.
On E, E each $= E + D - \frac{D'}{2} + L - \frac{L'}{2}$	$= 2063$ lbs., which $\times 2$	$= 4126$,,
On F, F each $= F + \frac{L'}{2} + \frac{G'}{2}$, or $\frac{8}{5}F$	$= 1866$,, ,, $\times 2$	$= 3732$,,
On H, H each $= H + G - \frac{G'}{2} + B - \frac{B'}{2}$	$= 2046$,, ,, $\times 2$	$= 4092$,,
On $A\,l = \frac{B'}{2} + 398$ lbs. $+ 441$ lbs. $+ 484$ lbs. $+ 97$ lbs.	$= 1914$,, ,, $\times 2$	$= 3828$,,
	Total . . .	$= 17300$,,

And to each of the weights on E, F and H may be added the weight of a purlin and block $= 100$ lbs. (Art. 43), making them respectively $= 2163$ lbs., 1966 lbs., and 2146 lbs.; also to the pressure on C add the weight of the ridge-pole $= 63$ lbs., making it $= 1585$ lbs.

46. The strains on those parts of the truss which lie below the struts h I, h I, fig. 20, will be the same as though the weight of the roof (excluding the portions which rest immediately on the walls) were concentrated at the apex c.

A reference to the figure will show that the roof there represented is supported at nine points, of which seven only rest on the truss, the remaining two A, A resting solely on the walls. Of the seven beams supported by the truss, one is the ridge-pole, the weight of which acts at c,[37] and the two adjoining are the purlins at E, E, which, pressing at the junction[38] of the straining beam with the principal rafters, produce the same strains as though they were united at c (Art. 8).

The two next beams are the central purlins at F, F, each of which acts on the apex of a triangle $a f$ K, producing one strain in direction of the length of the principal $f a$, and the other in direction of the length of the strut f K, which strains exert two equal and opposite horizontal thrusts at a and K.

[37] The two small upper principals are seldom used. In case of their omission, the weight at C would be supported by direct compression of the common rafters, provided their mutual resistance at the ridge-pole were such as to form a firm fulcrum there. This, however, is not always the case, especially if there be no purlin blocks. Often the weight of the roof causes the common rafters to separate a little from the ridge-pole, which may be obviated by clenching the ridge nails; but in either of these cases some considerable part of the weight at C must come on the upper purlins at E, E, while the weights at F, F will be lightened by the counterpoise. When the upper principals are omitted, the ridge-pole need be nothing more than a bond for the common rafters. A scantling of 4″ × 2″ would suffice for this.

[38] They press also slightly on the points $f f$, but the eventual strains are not thereby affected.

But besides the horizontal thrust at K, the strain on the strut f K causes a tension of the queen-post e K, and thus transfers a portion of the stress of the purlin at F to the point e.

We have now to consider the effects of the weights on the two lower purlins at H, H, each of which, resting at the top of a truss $a\,h$ I, causes strains in the directions of the length of the principal $h\,a$ and of the lower strut h I, as well as their two opposite horizontal thrusts at a and at I.[39] But the strain on h I acts also by tension on the rod f I, producing a stress at f which will have similar effects to those of the purlin at F already pointed out, one of which is to transfer a portion of the stress to the point e.

Now the portions of the stresses transferred from the two middle and the two lower purlins to e, e, produce the same strains as if united at c (Art. 8), and may be added to the stresses of the two upper purlins and ridge-pole, the whole being looked on as collected at the apex c.

And there remain three strains on each principal rafter, one of which, derived from the weight on F, and two from the weight on H, neither affect the upper part of that rafter nor the central division of the tie-beam. Nevertheless these strains, being in direction of the axes of the principals, are the same in regard to their lower extremities $h\,a$, $h\,a$, as if they were produced at e, e or at c; and it follows that the horizontal thrusts at a, a will also be the same as if those strains emanated from a weight at c.

It appears thus that the weight of this roof, excluding the parts supported immediately by the wall, acts on the extreme divisions of the principals and tie-beam, $h\,a$, $h\,a$ and I a, I a, as though it were concentrated at c.

47. A calculation in detail of the strains resulting from the weight of the roof will exhibit the same conclusion.

Let the letters A, H, F, E, C express the weights of the roof at those respective points. The weight of the truss, comparatively small, may for the present be neglected. The walls are the immediate supports of the weights A, A, and the effect of the weight C already at the apex need not be taken into account.

It remains then to compare the effect of the three pair of weights E E, F F, H H with what their effect would be if collected at c.

[39] Which opposite horizontal thrusts would be equal (Art. 3), if confined to $a\,h$ I as an independent truss vertically supported at I, but the obliquity of the suspending rod f I augments the horizontal strain in the direction from a to I.

The weights E E are supported, each by its purlin and purlin block,[40] through which it produces vertical strains at their points of pressure S and t, inversely proportional to the distances of those points from a vertical line E v. (Art. 4.) Consequently the effect of those strains on the fulcra between which their action lies, e and f, is the same as if they were united at v.

The weight F or F also acts through its purlin and block, but though this weight is exactly over the fulcrum f, its effect is not the same as though its two pressures were united at that point; because those pressures are on opposite sides of it, and act also in a small degree on the distant fulcra e and h and a. In the same manner the weights H, H each press on a and on f, as well as on h, and slightly tend to lift e. There must be, however, a certain point between each pair of fulcra, at which all the intervening pressures being united would produce the same effect, in regard to the fulcra, as when dispersed at their several positions. Let m mark this point between e and f, and n between f and h.

The horizontal distance from a to e is 17 feet, which is divided into $a\,h = 5'\cdot25$, $h\,f = 5'\cdot5$, $f\,v = 5'\cdot5$, and $v\,e = 0'\cdot75$. Also the horizontal distances of p, r and t from h, f and v respectively are each $= 0'\cdot375$,[41] and the distances of o, q, s from the same points each $= 1'\cdot125$.

Let the letters m, n, o, f, h express the weight causing deflection or the resistance to deflection, each at its site. Then the sum of all these resistances equals the sum of the weights, or $m + n + o + f + h = \mathrm{E} + \mathrm{F} + \mathrm{H}$. Also the sum of the resistances of the principal to deflection at f with the levers $f\,m$ and $f\,n$ will equal the sum of its resistances to deflection at m and at n with

[40] When the purlin blocks are omitted, which is very commonly the case, the office performed by them devolves on the common rafters, and through them a strain in direction of their slope, and equalling (when the upper principals are also omitted) the gravity of the roof (Art. 39), is conveyed to the wall-plate and ridge-pole. This force is often sufficient to turn the wall-plate as well as the purlins partly over, and to separate the rafters from the ridge-pole. To prevent such ill effects, the rafter nails at the ridge should be clenched. Both the purlin blocks and upper principals may then be omitted (an omission otherwise dangerous), but the upper purlins should be made stronger (Art. 46, note 37). An instance is known to the writer of a roof falling in from the drawing of the rafter nails at the ridge.

[41] The distance between the axes of the principal and common rafter is made $= 0'\cdot75$, and the points of action being assumed to lie in those lines, the distances of p from H h, of r from F f, and of t from E v, will, from the nature of the triangle, be each $= \frac{0'\cdot75}{2} = 0'\cdot375$, while the distance of a from $l\,l'$ will be $= 0'\cdot75 \times 2 = 1'\cdot5$, leaving $a\,\mathrm{S} = 1'$.

the same lever; and as in acting with the lever mf the pressure m exerts a force $= m \times \frac{me}{fe}$, and n acting with the lever nf exerts a force $= n \times \frac{nh}{fh}$, therefore f is $= m\frac{me}{fe} + n\frac{nh}{fh}$; and in like manner h is $= n\frac{nf}{fh} + o\frac{oa}{ha}$. Lastly, the pressures at o, p, q, r and v are, in the same sequence, $\frac{1}{4}$H, $\frac{3}{4}$H, $\frac{1}{4}$F, $\frac{3}{4}$F and E. Now the pressure on $o = \frac{H}{4}$ has to produce the deflections at o and at h, and in producing the latter it works with the lever ho being opposed by portions of the pressures on p and q, united by the supposition at n and working with the lever nh.

Thus the portion of pressure on o causing deflection		at	$h = h\frac{nh}{nh+ho}$.
Do.	on p and q	do.	at do. $= h\frac{oh}{nh+ho}$.
Do.	on do.	do.	at $f = f\frac{mf}{mf+fn}$.
Do.	on r, s, and t	do.	at do. $= f\frac{nf}{mf+fn}$.

Whence are derived the equations, $o + h\frac{nh}{no} = \frac{H}{4}$, $n + h\frac{oh}{no} + f\frac{mf}{mn} = \frac{3}{4}H + \frac{F}{4}$ and $m + f\frac{nf}{mn} = \frac{3}{4}F + E$. And from the foregoing five equations we deduce the value of $f = \left\{\left(E + \frac{3}{4}F\right) \times \frac{me}{ef} \times \left(\frac{no \times fh}{oh \times nh} + \frac{nf}{nh} + \frac{fh \times oa}{oh \times ha}\right) + \left(\frac{F}{4} + \frac{3}{4}H\right) \times \left(\frac{no}{oh} + \frac{oa \times nh}{oh \times ha}\right) - \frac{H}{4} \times \frac{oa}{ha}\right\} \div \left\{\left(\frac{no}{oh} + \frac{nf}{fh} + \frac{oa \times nh}{ha \times oh}\right) \times \left(\frac{fh}{nh} + \frac{fh \times nf \times me}{nh \times mn \times ef} + \frac{mf}{mn}\right) - \frac{mf \times nf}{fh \times mn}\right\}$.

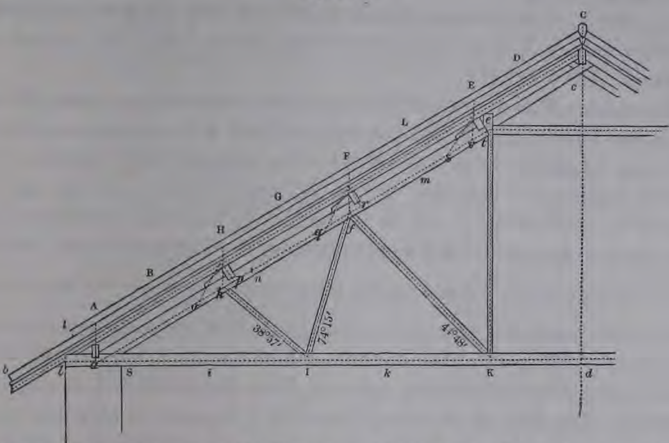
Before this value can be brought out in figures we must find the positions of m and n, the conditions of which give the equations, $mf\left(E + \frac{3}{4}F\right) = vf \times E + rf \times \frac{3}{4}F$, and $nf\left(\frac{F}{4} + \frac{3}{4}H\right) = qf \times \frac{F}{4} + pf \times \frac{3}{4}H$; and taking the values of E, F, H in ℔s. (Art. 45), we have $mf = 3'{\cdot}422525$ and $nf = 4'{\cdot}189255$;[42] whence substituting all those values in the equations for f, &c., we obtain $f = 1513{\cdot}27$ ℔s., $h = 847{\cdot}705$ ℔s., $m = 2804{\cdot}65$ ℔s., $n = 1029{\cdot}05$ ℔s., and $o = 80{\cdot}325$ ℔s., their total being 6275 ℔s. $=$ E + F + H.

It must now be noticed that in obtaining these results we have proceeded on the assumption of the principal rafter being of equal strength throughout;

[42] All the levers are given in their horizontal lengths.

whereas, in the instance before us, it is made, while retaining the same width, to decrease regularly from a to e in its depth, which at a is $= 7''\cdot3$ and at

Fig. 20 *b*.



$e = 4''\cdot75$, giving the rate of diminution $= 0''\cdot15$ in depth per horizontal foot of length. Now weights and lengths, or the stresses, their products, being equal, deflections are inversely, and resistances to deflection are directly, as the cubes of the depths of the divisions over which the deflections severally extend.[43] Thus, if f', h', m', n', o' express the corrected resistances, they will be to one another as f, h, m, n, o severally multiplied by the cubes of the medium depths of mn, no, ef, fh and ha, which are, in the same order, $5''\cdot746825^3 = 189\cdot7937$, $6''\cdot497425^3 = 274\cdot29875$, $5''\cdot21875^3 = 142\cdot1345$, $6''\cdot1^3 = 226\cdot981$, and $6''\cdot90625^3 = 329\cdot4025$; whence $f = 1529\cdot317$ ℔s., $h = 1238\cdot191$ ℔s., $m = 2122\cdot742$ ℔s., $n = 1243\cdot785$ ℔s., and $o = 140\cdot895$ ℔s.; also the

Vertical pressure on the fulcrum	$e = m\frac{mf}{ef}$	=	1163 ℔s.
Ditto	on $f = m\frac{me}{ef} + f + n\frac{nh}{fh}$	=	2786 ,,
Ditto	on $h = n\frac{nf}{fh} + h + o\frac{oa}{ha}$	=	2296 ,,
Ditto	on $a = o\frac{oh}{ha}$	=	30 ,,
	Total	=	6275 ,,

[43] Barlow's Essay.

The foregoing method of determining the pressures, however, is not only troublesome, but the correctness of its results may be doubted for reasons assigned in note to Art. 32; and for all practical purposes it may suffice, when the pressures, as in the truss before us, are not very far from the fulcra, to view the weights F, H as concentrated at the points f, h, in like manner as E was considered to act at v.

The weights F, H will, under this assumption, be entirely supported by their respective fulcra f and h; but the weight E will not only press on the two adjoining fulcra e and f as it would do if the principal were divided at f, but by the resistance to deflection at f, it will tend to lift h, and for the same reason its pressure on f will be increased. It has then to overcome two resistances to flexure, one at v and the other at f. The beam resists deflection at v with two levers, $v\,e$ and $v\,f$, the latter making $\frac{v\,e}{e\,f} = \frac{3}{25}$ of the whole resistance, which would also express the resistance to E of the compensating flexure at f produced by an equal weight at the end of the lever $f\,h$ ($f\,h$ being $= v\,f$) if the principal terminated at h, and were there disembarrassed of support or pressure. The value of the actual flexure at f, however, is only half that of the flexure produced under such conditions (Art. 33). Therefore, making $\frac{3}{25}$ of the resistance to deflection at $v = x$, the portion of the weight E required to produce the deflection at f would be $= \frac{x}{2}$, and we should have $E - \frac{x}{2}$ remaining for the deflection at v, and $x = \frac{3}{25}\left(E - \frac{x}{2}\right)$. But the resistance to deflection at f is greater in this instance than $\frac{x}{2}$ because the medium depth of the principal through the division $v\,h$ is $5''{\cdot}6875$, while the medium depth of $e\,f$ is $5''{\cdot}21875$; and the resistances being as the cubes of these depths, the weight required to bend f will be $\frac{x}{2} \times \frac{5{\cdot}6875}{5{\cdot}21875} = 0{\cdot}647\,x$, and $x = \frac{3}{25}(E - {\cdot}647\,x) = 0{\cdot}11135435\,E$. Also the pressure on f will be $x + 0{\cdot}647\,x +$ a counter-pressure from h equal to the latter $= 0{\cdot}25545$ E, and the pressure on e will be $E - x - 0{\cdot}647\,x = 0{\cdot}8166$ E, while the force tending to raise h will be $0{\cdot}647\,x = 0{\cdot}07205$ E.

The total vertical pressures on the fulcra thus found are $0{\cdot}8166$ E on e, $F + 0{\cdot}25545$ E on f and $H - 0{\cdot}07205$ E on h,[44] which pressures, their sum being $E + F + H$, call e, f, h, then,

[44] These pressures, when reduced to pounds from the values of E, F, H found in Art. 45, are,

1st, The pressures on e, e cause a direct strain on each principal .	$= 2e$	(Art. 39);
a compression of each end of the straining beam and a tension of each end of the tie-beam . .	$= 1{\cdot}732\,e$	(idem),
with a vertical strain on the latter	$= e$	(idem).
2nd, The pressures f, f cause a direct strain on each principal from f to a	$= {\cdot}7353f$	(Art. 41),
stretching the ends of the tie-beam with forces each $= {\cdot}7353f \times {\cdot}886$	$= {\cdot}6368f$	(Art. 39),
and weighing on them with forces each $= \frac{{\cdot}7353f}{2}$ . .	$= {\cdot}36765f$	(idem),
and a direct strain on each upper strut fK	$= {\cdot}8974f$	(Art. 41);
which latter causes horizontal thrusts at K, K each $= {\cdot}8974f \times {\cdot}7096$	$= {\cdot}6368f$	(idem),
and a vertical strain on each of the queen-posts eK $= {\cdot}8974f \times {\cdot}7046$	$= {\cdot}6323f$	(idem).
These vertical strains cause a direct strain on each principal $= {\cdot}6323f \times 2$	$= 1{\cdot}2646f$	(Art. 39),
a compression of each end of the straining beam and a tension of each end of the tie-beam $= {\cdot}6323f \times 1{\cdot}732$	$= 1{\cdot}0952f$,	
with a vertical pressure on the latter	$= {\cdot}6323f$.	
3rd, The pressures h, h produce a direct strain on each principal from h to a	$= {\cdot}8333\,h$	(Art. 41),

On $e = 1766$ ℔s., on $f = 2519$ ℔s., and on $h = 1990$ ℔s., which differ greatly from the pressures found by the method first used in this Article. A near approximation to the truth is probably attainable by supposing the weight F removed while the strains caused by E and H are determined, and then adding to them the strains due to F separately found. The pressures thus obtained, and corrected for the tapering of the principal, are, On $e = 1280$ ℔s., on $f = 2332$ ℔s., on $h = 2580$ ℔s., and on $a = 83$ ℔s. But to compare the results of the three methods in the fairest manner, we must suppose the principal to be of one scantling throughout, and discard the correction for tapering, because it affects them very unequally. They would in that case be,—By the 1st method, which finds the point of action m for the strains at r, s, t, and n for those at p and q, Pressure on $e = 1536$ ℔s., on $f = 3027$ ℔s., on $h = 1695$ ℔s., and on $a = 17$℔s. Total 6275 ℔s. By the 2nd method, which views the weights F, H as concentrated at f, h, Pressure on $e = 1796$ ℔s., on $f = 2456$ ℔s., on $h = 2023$ ℔s. By the 3rd method, which finds the pressures due to E and H combined, and to them adds those due to F, Pressure on $e = 1826$ ℔s., on $f = 2443$ ℔s., on $h = 1953$ ℔s., and on $a = 53$ ℔s. Hence it appears that the second and third methods (when undisturbed by the correction for tapering) furnish nearly coincident results. The first method is objectionable as proceeding on the supposition that the effects of the weight at q in producing flexure at h, and of p at f, are exactly as these weights and levers; whereas it may be doubted whether either of these pressures can be looked on as causing any fulcral deflection save at the fulcrum immediately adjoining it (note to Art. 32). For this reason the results got by the first method are not to be depended on, and it remains to choose between the two approximative methods, of which, the results not greatly differing, the second, as the simpler of the two, and more convenient for comparison because it exhibits no pressure on a, is here preferred.

extending the ends of the tie-beam with forces, each $= \cdot 8333\,h \times \cdot 866$	$= \cdot 7216\,h$,
and weighing on them with forces each $= \frac{\cdot 8333\,h}{2}$ . .	$= \cdot 41665\,h$,
and a direct strain on each lower strut h I . . .	$= \cdot 92795\,h$ (Art. 41);
which latter causes horizontal thrusts at I, I each $= \cdot 92795\,h \times \cdot 955$	$= \cdot 8862\,h$ (idem),
and a tension of each of the iron rods fI$= \cdot 92795\,h \times \cdot 6532$	$= \cdot 6061\,h$ (idem).
This tension is sustained by a part fa of each principal suffering a strain $= \cdot 6061\,h \times \cdot 9059$ . .	$= \cdot 5491\,h$ (idem),
which exerts a tension at each end of the tie-beam $= \cdot 5491\,h \times \cdot 866$	$= \cdot 4755\,h$,
with a vertical pressure on the same $= \frac{\cdot 5491\,h}{2}$	$= \cdot 2745\,h$,
and by each of the upper struts suffering a direct strain $= \cdot 6061\,h \times \cdot 7231$	$= \cdot 4382\,h$ (Art. 41),
which latter thrust horizontally at K, K with forces each $= \cdot 4382\,h \times \cdot 7096$	$= \cdot 3109\,h$,
and weigh on each of the queen-posts with a force $= \cdot 4382\,h \times \cdot 7046$	$= \cdot 3088\,h$;
and these last forces cause a direct strain on each principal $= \cdot 3088\,h \times 2$	$= \cdot 6176\,h$,
a compression of each end of the straining beam and a tension of each end of the tie-beam $\left.\right\} = \cdot 3088\,h \times 1\cdot 732$	$= \cdot 5349\,h$,
with a vertical pressure on the latter	$= \cdot 3088\,h$.

Recapitulation of the effects of the three pairs of weights.

Direct compression[45] of each principal rafter ea throughout	$= 2\,e + 1\cdot 2646 f + \cdot 6176\,h$.
Ditto of ditto from f to $a = \cdot 7353 f + \cdot 5491\,h$ + the above	$= 2\,(e + f) + 1\cdot 1667\,h$.
Ditto of ditto from h to $a = \cdot 8333\,h$ + the above . .	$= 2\,(e + f + h)$.
Direct tension of the tie-beam on each side from I to a $= 1\cdot 732\,e + \cdot 6368 f + 1\cdot 0952 f + \cdot 7216\,h + \cdot 4755\,h + \cdot 5349\,h$	$= 1\cdot 732\,(e + f + h)$.
Ditto of ditto on each side from K to I = the above $- \cdot 8862\,h$	$= 1\cdot 732\,(e + f) + \cdot 8458\,h$.
Ditto of ditto between K and K = the above $- \cdot 6368 f - \cdot 3109\,h$	$= 1\cdot 732\,e + 1\cdot 0952 f + \cdot 5349\,h$.
Weight on each end of tie-beam $= e + (\cdot 36765 + \cdot 6323)\,f + (\cdot 41665 + \cdot 2745 + \cdot 3088)\,h$	$= e + f + h$.
Direct compression of the straining beam e, e . .	$= 1\cdot 732\,e + 1\cdot 0952 f + \cdot 5349\,h$.
Ditto of each of the upper struts f K	$= \cdot 8974 f + \cdot 4382\,h$.
Ditto of each of the lower struts h I	$= \cdot 92795\,h$.
Direct tension of either of the queen-posts K e . .	$= \cdot 6323 f + \cdot 3088\,h$.
Ditto of either of the iron rods If	$= \cdot 6061\,h$.

Now if these three pairs of weights were collected at c, their joint pressure $2\,(e + f + h) = 2\,(\mathrm{E} + \mathrm{F} + \mathrm{H})$ would act on the upper principals $c\,e$, $c\,e$ with

[45] The compression or tension of a beam is that of one end only.

strains each $= 1{\cdot}836 \times (e + f + h)$ (note to Art. 39), causing vertical pressures at e, e each $= e + f + h$, and horizontal thrusts there each $= {\cdot}1{\cdot}5398\,(e + f + h)$ (note to Art. 39).

The vertical pressures at e, e would cause a direct strain on each principal $e\,a$	$= 2\,(e + f + h)$,
a compression of each end of the straining beam and a tension of each end of the tie-beam . . .	$= 1{\cdot}732\,(e + f + h)$,
with a vertical pressure on the latter	$= e + f + h$,

and no strain on the struts, queen-posts, or rods. The straining beam also would be unaffected, were the slope of the upper and lower principals the same, because in that case the tension and compression would cancel one another.

On comparing the effects then of the weights E, E, F, F, H, H, placed at those points (fig. 20), and of the same weights collected at c, we find them identical in regard to the extremities of the principals and tie-beam, $h\,a$, $h\,a$, and I a, I a, though not otherwise agreeing.

48. The weight of the truss is distributed in the following manner:

One of the small upper principals $c\,e$, weighing[46] . . .	= 10·8440 lbs.	(Art. 43).
Half of $e\,e$, the straining beam	= 28·3740 ,,	(idem).
Part of $e\,f$, the upper division of one principal[47] . . .	= 24·7565 ,,	
One of the queen-posts e K	= 46·3734 ,,	(Art. 43).
Part of S S, the tie-beam supported by it[48]	= 63·8508 ,,	
Half of Kf, one of the upper struts	= 18·6910 ,,	(Art. 43).
Total . . .	= 192·8897 ,,	resting on e.

[46] 6·0244 lbs. of this weight may be said more correctly to be supported at c, but the effect is the same when the whole is considered to be supported at e, except as regards the strain of the rafter itself.

[47] The principal rafter, exclusive of its tenons, is 18′·98 long, and weighs 184·6 lbs. (Art. 43), namely,

$$\begin{aligned} \text{Upper division} &= 6'{\cdot}98 \times 5'' \times 5''{\cdot}2 = 58{\cdot}7 \text{ lbs.} \\ \text{Central ditto} &= 6'{\cdot}35 \times 5'' \times 6''{\cdot}1 = 62{\cdot}6 \text{ ,,} \\ \text{Lower ditto} &= 5'{\cdot}65 \times 5'' \times 6''{\cdot}93 = 63{\cdot}3 \text{ ,,} \end{aligned}$$

from which, by the method explained in Art. 38, are found the values of the medial and fulcral deflections, and these, corrected for the tapering of the beam (Art. 47), give the pressures on the fulcra as above.

[48] The weight of the tie-beam is 363·7696 lbs. (Art. 43), of which the portion from S to S is distributed among its points of support in the same proportions as the weight of the ceiling (Art. 49).

Part of the upper and central divisions of one principal .	= 63·0241 lbs.	
Half of one of the upper struts	= 18·6910 ,,	
Half of one of the iron rods f I	= 5·4070 ,,	
Total	= 87·1221 ,,	resting on f.

Half of one of the iron rods	= 5·4070 lbs.	
Part of the tie-beam supported by it	= 67·9051 ,,	
Half of I h, one of the lower struts	= 4·2015 ,,	
Total	= 77·5136 ,,	resting on I.

Parts of the central and lower divisions of one principal .	= 73·3658 lbs.	
Half of one of the lower struts	= 4·2015 ,,	
Total	= 77·5673 ,,	resting on h.

Part of the lower division of one principal . . .	= 23·4702 lbs.	
One end of the tie-beam	= 50·1294 ,,	
Total	= 73·5996 ,,	resting on the wall.

RECAPITULATION.

Weight of truss resting	on e .	= 192·8897 lbs.	
Ditto	on f .	= 87·1221 ,,	
Ditto	on I .	= 77·5136 ,,	
Ditto	on h .	= 77·5673 ,,	
Ditto	on the wall	= 73·5996 ,,	
Total	.	= 508·6923 ,,	which × 2 = 1017·3846 lbs. (Art. 43).

There are certain parts, it will be observed, in the foregoing distribution, described as resting on I, which could not be classed with weights at f, because, acting through the oblique rod f I, they produce effects at f differing from those of a weight vertically suspended therefrom. These effects are, I being supposed to express the weight at I,

A horizontal thrust on I K	= ·282 I	(Art. 41).
A tension of the iron rod f I	= 1·039 I	(idem).
This tension causes a direct strain on a part $f\,a$ of the principal = 1·039 I × ·9059	= ·9412 I	(idem),
which extends the tie-beam at a with a force = ·9412 I × ·866	= ·8151 I	(Art. 39),
also producing a vertical pressure there = $\frac{\cdot 9412\ \mathrm{I}}{2}$	= ·4706 I	(idem),
and a thrust on the upper strut f K = 1·039 I × ·7231 . .	= ·7531 I	(Art. 41),
which pushes horizontally at K with a force = ·7513 I × ·7096	= ·5331 I	(idem),
and weighs on the queen-post e K with a force = ·7513 I × ·7046	= ·5294 I	(idem).

The latter weight strains the principal $e\,a$ directly with a force $= \cdot5294\,\mathrm{I} \times 2$		$= 1\cdot0588\,\mathrm{I}$ (Art. 39).
causing a compression of the straining beam and a tension of the tie-beam . .	each $= \cdot5294\,\mathrm{I} \times 1\cdot732$.	$= \cdot9169\,\mathrm{I}$ (idem).
with a vertical pressure on the latter		$= \cdot5294\,\mathrm{I}$.

Recapitulation of the effects of a weight at I.[49]

Direct compression of the principal rafter $e\,a$ throughout		. . .	$= 1\cdot0588\,\mathrm{I}$.
Ditto	ditto	from f to a = the above $+ \cdot9412\,\mathrm{I}$	$= 2\,\mathrm{I}$.
Direct tension of the tie-beam from I to $a = (\cdot8151 + \cdot9169)\,\mathrm{I}$		. .	$= 1\cdot732\,\mathrm{I}$.
Ditto	ditto	from K to I = the above $- \cdot282\,\mathrm{I}$ . .	$= 1\cdot45\,\mathrm{I}$.
Ditto	ditto	between K and K = the above $- \cdot5331\,\mathrm{I}$.	$= 9169\,\mathrm{I}$.
Vertical pressure on the tie-beam at $a = (\cdot4706 + \cdot5294)\,\mathrm{I}$		. . .	$= \mathrm{I}$.
Direct compression of the straining beam $e\,e$		. . . . . .	$= \cdot9169\,\mathrm{I}$.
Ditto	of the upper strut f K	. . . .	$= \cdot7513\,\mathrm{I}$.
Direct tension of the queen-post e K		. . . .	$= \cdot5294\,\mathrm{I}$.
Ditto	of the iron rod f I	. . . .	$= 1\cdot039\,\mathrm{I}$.

Showing that the effects on $f\,a$ and I a are the same as if the weight I were at e, or the pair of weights I, I at c (Art. 8).

49. The weight of a chunam ceiling resting on one truss would be 5722·5 tbs. For the span $\mathrm{S\,S} = 40' \times$ distance between the trusses $= 10' \times$ the weight per square foot $= 14\cdot3061$ tbs. (Art. 44), gives 5722·44 tbs., one-fifth of which weight is uniformly spread over each of the five compartments, K K in the centre, and K I, I S on either side. The whole weight has to produce eleven deflections, of which five are on these compartments and six on the points of support, but of the latter deflections the two at S S offer only half of the resistance due to their compensating medial deflections at i, i, because the pressure of the principals at a, a produces the effect of the cross-beam in figure 16 (Art. 33).

Let the letter at each point express the value of the deflection there; also, as i, i, k, k, will not uniformly pervade their respective divisions, let i', i', k', k' be the weights which, uniformly pervading those divisions, would produce the same deflections (Art. 38). Then $i + \frac{\mathrm{S}}{2} + \frac{\mathrm{I}}{2} = 1144\cdot5$ tbs., $k + \frac{\mathrm{I}}{2} + \frac{\mathrm{K}}{2} = 1144\cdot5$ tbs. and $d + \mathrm{K} = 1144\cdot5$ tbs.; whence $2\,i + 2\,k + d + 2\,\mathrm{I} + 2\,\mathrm{K} + \mathrm{S} = 5722\cdot5$ tbs. Also $\frac{i' + k'}{2} = \frac{3}{5}\mathrm{I}$, $\frac{k' + d}{2} = \frac{3}{5}\mathrm{K}$ and $\frac{i'}{2} = \frac{3}{5}\mathrm{S}$. And to find the

[49] Notice that this weight at I is only one of two equal weights at I, I, and that its strain is not therefore calculated farther than to the end of the straining beam, where it is met by an equal strain arising from the weight at the opposite I.

values of i' and k', we have $\left(\frac{I}{2}-\frac{S}{2}\right)\times\frac{3}{2}+i-\left(\frac{I}{2}-\frac{S}{2}\right)$ or $i+\frac{I}{4}-\frac{S}{4}=i$, and $\left(\frac{I}{2}-\frac{K}{2}\right)\times\frac{3}{2}+k-\left(\frac{I}{2}-\frac{K}{2}\right)$ or $k+\frac{I}{4}-\frac{K}{4}=k'$, the substitution of which values in the three preceding equations gives, $i+k=\frac{7}{10}I+\frac{S}{4}+\frac{K}{4}$, $k+d=\frac{29}{20}K-\frac{I}{4}$, and $i=\frac{29}{20}S-\frac{I}{4}$. Hence, with the aid of the three leading equations we deduce,

$i=492{\cdot}520569$ lbs.	which $\times\ 2 =$	$985{\cdot}041138$ lbs.	Also $i'=577{\cdot}771966$ lbs.
$k=380{\cdot}143727$,,	,, $\times\ 2 =$	$760{\cdot}287454$,,	$k'=409{\cdot}206703$,,
$d=438{\cdot}269678$,,	. . . $=$	$438{\cdot}269678$,,	
$I=822{\cdot}482224$,,	which $\times\ 2 =$	$1644{\cdot}964448$,,	
$K=706{\cdot}230322$,,	,, $\times\ 2 =$	$1412{\cdot}460644$,,	
$S=481{\cdot}476638$,,	. . . $=$	$481{\cdot}476638$,,	
	Total	$5722{\cdot}5$,,	

And the pressures on the fulcra will be,

On $K=K+\frac{d}{2}+\frac{k'}{2}$	. . . . .	$=1130$ lbs.
On $I=I+k-\frac{k'}{2}+i-\frac{i'}{2}$	. .	$=1201{\cdot}75$,,
On $S=\frac{S}{2}+\frac{i'}{2}$	. . . . . .	$=529{\cdot}5$,,
Total	. . .	$=2861{\cdot}25$,, which $\times\ 2=5722{\cdot}5$ lbs.

And for the effect of these weights on I, I see the preceding Article, while the weights at K, K being vertically suspended from *e e*, act from those points, as any other weights there would do.

50. Fig. 21 being drawn to represent the same roof as fig. 20, let us suppose a wind blowing horizontally and equally against the face *b* R. Its force would be received and divided by the five supports A *l*, H, F, E and C, the stress on each of which let us proceed to determine.

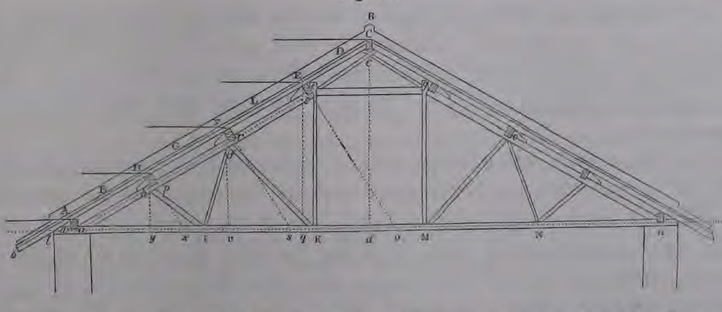
The effective power of a horizontal force on the surface of a roof sloping at an angle of 30°, is just the half of what it would be against a vertical surface of the same dimensions (Art. 40). In other words, a vertical screen of equal height with the roof, and consequently of half its surface (Art. 39), would be exposed to equal stress, and would offer equal resistance, and the size of such a screen, extending from one truss to another, would be $\frac{25'}{2}\times 1{\cdot}1547\times 10'$ $=144{\cdot}3375$ square feet, to which add $\frac{5'}{6}\times 10'=8{\cdot}3333$ square feet for the depth of the roof at the ridge from the battens upwards, total 152·671 square feet; which × 57·75 lbs.,[50] gives the whole force of the wind at its greatest velocity against the face b R = 8816·75 lbs.

This force may be described as under (Art. 45):

Stress from	R to C =	9·77 square feet	×	57·75 lbs.	=	564 lbs.
Ditto	C to F =	27·43 ,,	×	ditto	=	1584 ,,
Ditto	E to F =	31·75 ,,	×	ditto	=	1834 ,,
Ditto	F to H =	ditto ,,	×	ditto	=	1834 ,,
Ditto	H to A =	ditto ,,	×	ditto	=	1834 ,,
Ditto	A to l =	7·22 ,,	×	ditto	=	417 ,,
Ditto	l to b =	13·[51] ,,	×	ditto	=	750 ,,
				Total	=	8817 ,,

Now to determine the stress arising from flexure at the point A, we have the force from l to b = 750 lbs., acting with lever, which, taken vertically, is = ·65[52] = 487·5 lbs. × 1′, opposed in the first place by the force on l A = 417 lbs. × ·′361 = 150·5 lbs. × 1′, and its residue = 337 lbs. × 1′, supposed to be poised by a part of the force on A B, pervading the half of that space nearest to A, = 425 lbs. × lever ·′79375, the product of which is 337 lbs. In like manner we have at C the force on R C = 564 lbs. × lever ·′4885 = 275·5 lbs. × 1′ balancing 402 lbs. × lever ·′68575 spread over the half of C E.

Fig. 21.



50 The extreme force of wind at its greatest observed velocity is stated in Tredgold's 'Essay on Cast Iron' (Table of data, 'Wind'), at $57\frac{3}{4}$ lbs. per square foot. The force of a violent hurricane that tears up trees, overturns buildings, &c., is given at 51·426 lbs. per square foot. In the same Table ('Roofs'), the greatest force of the wind on a superficial foot of roofing is computed at 40 lbs.

51 (1′·443 − ·1443 = half depth of rafter) × 10′ = 13 square feet.

52 This and the following levers are all taken according to their vertical projections.

And let E, F, H represent the remaining fulcral resistances to flexure, and B, G, L, D the medial resistances, B′, G′, L′, D′ being supposed equivalents of the latter, if uniformly pervading their respective intervals (Art. 38). Then, from equations similar to those used in Art. 45, are derived[53]—

B = 771·7459 lbs.	Also B′ = 877·8729 lbs.
G = 620·8552 ,,	G′ = 651·5369 ,,
L = 716·5526 ,,	L′ = 733·7197 ,,
D = 555·5172 ,,	D′ = 667·7586 ,,
E = 1168·0394 ,,	
F = 1151·7815 ,,	
H = 1274·5082 ,,	
Total = 6259· ,,	

And the pressures on the fulcra will be,

$$\text{On C} = 564 \text{ lbs.} + 462 \text{ lbs.} + \frac{D'}{2} \quad \ldots \quad = 1300 \text{ lbs.}$$

$$\text{On E} = E + D - \frac{D'}{2} + \frac{L'}{2} \quad \ldots \quad = 1757 \text{ ,,}$$

$$\text{On F} = F + L - \frac{L'}{2} + \frac{G'}{2} \quad \ldots \quad = 1827 \text{ ,,}$$

$$\text{On H} = H + G - \frac{G'}{2} + B - \frac{B'}{2} \quad \ldots \quad = 1902 \text{ ,,}$$

$$\text{On A}l = \frac{B'}{2} + 425 \text{ lbs.} + 417 \text{ lbs.} + 750 \text{ lbs.} \quad \ldots \quad = 2031 \text{ ,,}$$

$$\text{Total} \quad \ldots \quad = 8817 \text{ ,,}$$

51. The force of the wind on each of the five supports A *l*, H, F, E and C being known, it remains to determine in what proportions the four latter, resting on the truss, would distribute their shares through its timbers. Let the letters C, E, F, H express the stress of the wind, each at its respective place; then,

1st. The stress C may be conceived to act either by tension and compression of the common rafters only, or more correctly, by tension of the common rafters C A and pressure through the ridge-pole on the truss *c e g* at *c*. For as the ridge-pole rests loosely on the truss, and the upper principals are supposed to be merely mortised into the straining beam, it is obvious that the principal *c e* can offer no resistance to tension, which must fall entire on the common rafters C A. On the other hand, it is probable that the pressure would be

[53] In consequence of $\frac{2743}{5918}$ E proving to be less than $\frac{F}{2}$, one of the equations becomes altered to $L' = L - \frac{2743}{11836} E + \frac{F}{4}$, the signs of the two latter quantities being reversed, and this alteration also affects two of the dependent equations.

borne chiefly, if not altogether, by the truss $c\,e\,g$, because the common rafters are, from the weight of the tiles and their inclined position, in a state of tension unfavourable to their resisting direct pressure. Let then $w\,d$ represent the stress C. The direct tension of the common rafters would be expressed by $C\,A = 1{\cdot}1547\ C$ (Art. 39), and the vertical pressure on the ridge-pole would be expressed by $C\,d = {\cdot}6113\ C$.[54]

The tension of the rafters acts on the tie-beam through the wall-plate,[55] producing at w

A horizontal strain	$= C$,
and a vertical strain	$= {\cdot}6113\ C$;
which latter tends to lift a with a force $= {\cdot}6113\ C \times \frac{w\,n = 42'{\cdot}25}{a\,n = 42'}$	$= {\cdot}61495\ C$,
and presses on n with a force $= 6113\ C \times \frac{w\,a = {\cdot}'25}{a\,n}$ . .	$= {\cdot}00365\ C$.
The pressure at C acts on each of the two upper principals with a direct strain $= {\cdot}6113\ C \times {\cdot}918$	$= {\cdot}5612\ C$ (note to Art. 39);
producing horizontal strains at e and g each $= {\cdot}6113\ C \times {\cdot}7699$	$= {\cdot}47065\ C$ (idem),
and vertical strains there each $= \frac{{\cdot}6113\ C}{2}$	$= {\cdot}30565\ C$;
the latter causing direct strains of the lower principals, each $= {\cdot}30565\ C \times 2$	$= {\cdot}6113\ C$ (Art. 39),
a compression of each end of the straining beam and a tension of each end of the tie-beam $= {\cdot}30565\ C \times 1{\cdot}732$	$= {\cdot}5294\ C$ (idem),
with a vertical pressure on the latter	$= {\cdot}30565\ C$.

[54] $l\,w$ is $= 1'{\cdot}25$ and $w\,d = 21'{\cdot}25$, whence $l\,w = \frac{1{\cdot}25}{21{\cdot}25}\ C = {\cdot}0588\ C$, and $C\,d = 1{\cdot}0588\ C \times {\cdot}57735 = {\cdot}6113\ C$ (Art. 39).

[55] The resistance of the wall-plate being supposed insufficient, it may be said that a part of the strain might come on the purlins, and through them on the principal $e\,a$, which, being only let into the tie-beam, and therefore incapable of resisting by tension, would be pressed upwards, and being met by the straining beam and queen-post, would through them compress the opposite principal $g\,n$, besides causing other strains. To this it may be answered, that the resistance of the common rafter to tension arises, not from its connection alone with the wall-plate and purlins, but from its counter-tension by the weight of the roof resting on it. For suppose all connection removed except at the ridge-pole, the rafter simply lying on the purlins and wall-plate: before the rafter thus situated could be moved, it would be necessary to apply at C a horizontal force equal, when acting with the lever of its height and opposed by the lever of its span, to raise half the weight of the roof. It is true that the weight of the two slopes being exactly balanced, any derangement of that balance by the wind would expose the truss to new strains *pro tanto*, but there is a portion of the roof resting on the wall to which this objection is not applicable, and which is more than sufficient to resist the utmost lifting power of the wind. Pressure on the wall and plate A l, fig. 20 = 1914 lbs. (Art. 45). Lift by the wind at a, fig. 21 = 1315 lbs. (note to recapitulation of strains in this Article).

2nd. The stress E acting at the top of the purlin Et will press it in direction of its depth, at the same time causing a tension of the common rafters E b. Draw E o perpendicular to E b, and let $w\,o$ represent the stress E, then E o = ·5279 E [56] will express the pressure on the purlin, and E A = ·8499 E will be the tension of the rafters (note at foot),

which latter exerts a horizontal force at $w = w\,q$ . .	$= {\cdot}73606$ E (idem),
with a vertical force there = E q	$= {\cdot}4571$ E (idem),
the lifting power of which at a is $= {\cdot}4571 \text{ E} \times \frac{w\,n}{a\,n}$.	$= {\cdot}4598$ E,
and its pressure at $n = {\cdot}4571 \text{ E} \times \frac{w\,a}{a\,n}$	$= {\cdot}0027$ E.

The pressure on the purlin acts at a horizontal distance of ·′375 from e and of 5′·875 from f, and while it presses on both these fulcra it tends to lift h. However, to simplify the calculation, the strains may be considered as confined to the two former, in which case e will sustain $\frac{t\,f}{e\,f} \times {\cdot}5279 \text{ E} = {\cdot}4962 \text{ E}$, and f will carry $\frac{t\,e}{e\,f} \times {\cdot}5279 \text{ E} = {\cdot}0317 \text{ E}$.[57] The strain on f may be taken into account with other strains at that point, to be considered hereafter; and as F will also press on e, let the united amount of strains there be termed e, which, acting at right angles to the principal $e\,a$, will cause

a pressure in direction of its length	$= {\cdot}1{\cdot}732\,e$	(Art. 39),
a horizontal thrust at e	$= 2\,e$	(idem),
an opposite horizontal thrust at $a = 1{\cdot}732\,e \times {\cdot}866$ . .	$= 1{\cdot}5\,e$	(idem),
with a vertical pressure at a	$= {\cdot}866\,e$	(idem).

The horizontal thrust at e acts through the straining beam at the apex g of the triangle g M n, and exerts a direct strain on the principal $g\,n = 2\,e \times 1{\cdot}1547 = 2{\cdot}3094\,e$ (Art. 39),

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[56] $l\,q$ is $= 17'{\cdot}75$ and by similar triangles $q\,o = \frac{l\,q}{3} = 5'{\cdot}9166$; whence $w\,o = l\,o - l\,w = 22'{\cdot}4166$, $\text{E}\,o = \frac{2\,q\,o}{w\,o} \text{E} = {\cdot}5279 \text{ E}$, and $\text{E A} = \frac{1{\cdot}1547\,w\,q}{w\,o} \text{E} = {\cdot}8499 \text{ E}$, also $w\,q = \frac{16{\cdot}5}{w\,o} \text{E} = {\cdot}73606 \text{ E}$, and $\text{E}\,q = {\cdot}866 \text{ E}\,o = {\cdot}4571 \text{ E}$.

[57] To find the distribution of the pressure more accurately, call $\frac{t\,e}{e\,f}$ or $\frac{3}{50}$ of the resistance to deflection at $t = x$. The weight required to bend f will be $\frac{x}{2} \times \frac{5''{\cdot}659375^3}{5{\cdot}21875^3} = {\cdot}63764\,x$, and $x = \frac{3}{50} \times ({\cdot}5279 \text{ E} - {\cdot}63764\,x) = {\cdot}0305 \text{ E}$. The pressure on e is $= {\cdot}5279 \text{ E} - 1{\cdot}63764\,x = {\cdot}47795 \text{ E}$, on $f = 2{\cdot}27528\,x = {\cdot}0694 \text{ E}$, and on $h = -\,{\cdot}63764\,x = -\,{\cdot}01945 \text{ E}$ (Art. 47).

producing a horizontal strain at n . . . . . . $= 2\,e$,
and a vertical pressure there . . . . . . $= 1{\cdot}1547\,e$;
while it extends the queen-post g M with a force . . $= 1{\cdot}1547\,e$,
which pushes up the strut M O with a force $= \frac{1{\cdot}1547\,e}{{\cdot}7046}$. $= 1{\cdot}6387\,e$ (Art. 41),
compressing the tie-beam from M to a with $1{\cdot}6387\,e \times {\cdot}7096$ $= 1{\cdot}1628\,e$.
The pressure on the strut extends the rod O N with $\frac{1{\cdot}6387\,e}{{\cdot}7231}$. $= 2{\cdot}2663\,e$,
and compresses the principal from O downwards with $2{\cdot}2663\,e \times {\cdot}9059$ . . . . $= 2{\cdot}053\,e$,
making a horizontal thrust at $n = 2{\cdot}053\,e \times {\cdot}866$ . . $= 1{\cdot}7779\,e$,
and a vertical pressure there $= \frac{2{\cdot}053\,e}{2}$ . . . . . $= 1{\cdot}0265\,e$.
The strain of the rod may be resolved into a transverse strain of the tie-beam at $\mathrm{N} = \frac{2{\cdot}2663\,e}{1{\cdot}039}$ . . . . . $= 2{\cdot}1812\,e$,[58]
and a push in direction N $a = 2{\cdot}1812\,e \times {\cdot}282$ . . . $= {\cdot}6151\,e$,
the transverse force exerting a lift at $n = 2{\cdot}1812\,e \times \frac{33'}{42'}$. $= 1{\cdot}7138\,e$,
and a lift at $a = 2{\cdot}1812\,e \times \frac{9'}{42'}$ . . . . . . $= {\cdot}4674\,e$.

3rd. The stress F presses on the purlin F r in a direction F s perpendicular to the common rafters F b, on which it exerts at the same time a tension $=$ F A $= {\cdot}8421$ F, $w\,s$ representing F, and F $s = {\cdot}5414$ F expressing the pressure on the purlin.[59]

The tension of the rafters exerts at w

a horizontal force $= w\,v$ . . . . $= {\cdot}7293$ F (note at foot),
with a vertical force there $=$ F v . . . . . . $= {\cdot}4689$ F (idem),
the lifting power of which at a is $= {\cdot}4689\ \mathrm{F} \times \frac{w\,n}{a\,n}$ . . $= {\cdot}4717$ F,
and its pressure at n is $= {\cdot}4689\ \mathrm{F} \times \frac{w\,a}{a\,n}$ . . . . $= {\cdot}0028$ F.

The pressure on the purlin in direction F s acts at a horizontal distance from $f = {\cdot}'375$, and from $e = 5'{\cdot}875$, and supposing its action confined to these two fulcra, its pressure on f would be $\frac{r\,e}{e\,f} \times {\cdot}5414\ \mathrm{F} = {\cdot}5089$ F, and on $e =$

[58] The strain of the rod must be met here by the transverse strength of the tie-beam alone, for the lower strut can offer no resistance, abutting as it does simply on the principal, the action of which on one of its fulcra O would be to cause a tension of the iron rod, and to repeat the same circle of strains perpetually.

[59] $l\,v$ is $= 12'{\cdot}25$, and by similar triangles $v\,s = \frac{l\,v}{3} = 4'{\cdot}0833$; whence $w\,s = l\,s - l\,w = 15'{\cdot}0833$, F $s = \frac{2\,v\,s}{w\,s}$ F $= {\cdot}5414$ F, and F A $= \frac{1{\cdot}1547\,w\,v}{w\,s}$ F $= {\cdot}8421$ F; also $w\,v = \frac{11'}{w\,s}$ F $= {\cdot}7293$ F, and F $v =$ ${\cdot}866$ F $s = {\cdot}4689$ F.

$= \frac{rf}{ef} \times \cdot 5414\,F = \cdot 0325\,F$, which latter forms a portion of e, the effects of which have been discussed already. Call the combined strains at $f = f$, and this, acting at the vertex of the triangle afK, will cause a pressure in direction $fa = \cdot 2717 f$ (Art 40),

which produces a horizontal strain at $a = \cdot 2717 f \times \cdot 866$.	$= \cdot 2353 f$,
and a vertical strain there $= \frac{\cdot 2717 f}{2}$	$= \cdot 13585 f$,
with a pressure on the strut fK	$= 1 \cdot 03625 f$ (Art. 40),
which makes a horizontal thrust at $K = 1 \cdot 03625 f \times \cdot 7096$.	$= \cdot 7353 f$,
and a direct tension of the queen-post $Ke = 1 \cdot 03625 f \times \cdot 7046$	$= \cdot 73015 f$.
The tension of the queen-post compresses ea with $\cdot 73015 f \times 2$.	$= 1 \cdot 4603 f$,
and eg with a force $= \cdot 73015 f \times 1 \cdot 732$	$= 1 \cdot 2647 f$,
the compression of ea causing a horizontal thrust at a . .	$= 1 \cdot 2647 f$,
with a vertical pressure there	$= \cdot 73015 f$.
Meantime the compression of the straining beam eg produces a direct pressure on the principal $gn = 1 \cdot 2647 f \times 1 \cdot 1547$	$= 1 \cdot 4603 f$,
and through it a horizontal thrust at n	$= 1 \cdot 2647 f$,
with a vertical pressure there	$= \cdot 73015 f$,
also a counter-tension of the queen-post gM	$= \cdot 73015 f$,
which causes a pressure on the strut $MO = \frac{\cdot 73015 f}{\cdot 7046}$ . .	$= 1 \cdot 03625 f$,
and a pressure on the tie-beam in direction $Ma = 1 \cdot 03625 f \times \cdot 7096$	$= \cdot 7353 f$.
The pressure upwards on the strut causes a tension of the rod $ON = \frac{1 \cdot 03625 f}{\cdot 7231}$	$= 1 \cdot 4331 f$,
and compresses On with a force $= 1 \cdot 4331 f \times \cdot 9059$ . .	$= 1 \cdot 2982 f$,
producing a horizontal thrust at $n = 1 \cdot 2982 f \times \cdot 866$ . .	$= 1 \cdot 1242 f$,
and pressing vertically there with a force $= \frac{1 \cdot 2982 f}{2}$ . .	$= \cdot 6491 f$.
The tension of the rod is met by a transverse resistance of the tie-beam at $N = \frac{1 \cdot 4331 f}{1 \cdot 039}$	$= 1 \cdot 3793 f$,
and by a horizontal resistance at $N = 1 \cdot 3793 f \times \cdot 282$.	$= \cdot 3889 f$,
the transverse lift acting at n with a force $= 1 \cdot 3793 f \times \frac{33'}{42'}$.	$= 1 \cdot 0837 f$,
and at a with a force $= 1 \cdot 3793 f \times \frac{9'}{42'}$	$= \cdot 2956 f$.

4th. The stress H presses on the purlin Hp in the direction Hx of its depth, and causes at the same time a tension of the common rafters Hb, and if wx represent the force $H, Hx = \cdot 58065\,H$, and $HA = \cdot 8195\,H$, will respectively express the pressure and tension,[60]

[60] lq is $= 6' \cdot 75$, and by similar triangles $yx = \frac{lq}{3} = 2' \cdot 25$; whence $wx = lx - lw = 7' \cdot 75$,

which latter causes a horizontal strain at $w = w\,y$ . .	$= \cdot7097\,\text{H}$ (note at foot),
with a vertical strain there $= \text{H}\,y$	$= \cdot5028\,\text{H}$ (idem),
the lifting force of which at a is $= \cdot5028\,\text{H} \times \frac{w\,n}{a\,n}$ . .	$= \cdot5058\,\text{H}$,
and its pressure at n is $= \cdot5028\,\text{H} \times \frac{w\,a}{a\,n}$	$= \cdot003\,\text{H}$.

The pressure on the purlin acts in direction $\text{H}\,x$, at a horizontal distance from $h = \cdot'375$ and from $f = 5'\cdot125$; and supposing, as before, its action limited to those two fulcra, the former would bear $\frac{p\,f}{f\,h} \times \cdot58065\,\text{H} = \cdot0396\,\text{H}$, and the latter $\frac{p\,h}{f\,h} \times \cdot58065\,\text{H} = \cdot54105\,\text{H}$.[61] Of these the former was included in f, and calling the latter h, its effects will be,

A direct pressure of $h\,a$	$= \cdot38486\,h$ (Art. 40),
which causes a horizontal push at $a = \cdot38486\,h \times \cdot866$.	$= \cdot3333\,h$,
with a vertical pressure there $= \frac{\cdot3848\,h}{2}$	$= \cdot1924\,h$,
and a pressure on the strut $h\,\text{I}$	$= 1\cdot0715\,h$ (Art. 40),
making a horizontal push at $\text{I} = 1\cdot0715\,h \times \cdot955$ . .	$= 1\cdot0233\,h$,
and a tension of the rod $\text{I}f = 1\cdot0715\,h \times \cdot6532$ . .	$= \cdot6999\,h$.
The tension of the rod causes a direct strain of $f\,a = \cdot6999\,h \times \cdot9059$	$= \cdot634\,h$,
which acts on the tie-beam at a with a push $= \cdot634\,h \times \cdot866$	$= \cdot5491\,h$,
and with a vertical pressure $= \frac{\cdot634\,h}{2}$	$= \cdot317\,h$,

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$\text{H}\,x = \frac{2\,y\,x}{w\,x}\,\text{H} = \cdot58065\,\text{H}$ and $\text{H}\,\text{A} = \frac{1\cdot1547\,w\,y}{w\,x}\,\text{H} = \cdot8195\,\text{H}$. Also $w\,y = \frac{5'\cdot5}{w\,x}\,\text{H} = \cdot7097\,\text{H}$, and $\text{H}\,y = \cdot866\,\text{H}\,x = \cdot5028\,\text{H}$.

[61] The strains caused by F and H may be found more accurately by the following equations, in which the letters f, h, p, r express the resistances to deflection at those points (Art. (47). $r + \frac{p\,f}{p\,r}f = \cdot5414\,\text{F}$, $p + \frac{r\,f}{p\,r}f + \frac{a\,h}{p\,a}\,h = \cdot58065\,\text{H}$, also $\frac{r\,e}{e\,f}r + \frac{p\,h}{f\,h}p = f$ and $\frac{p\,f}{f\,h}p = 2\,h$; whence are found the values of $f = \cdot2708\,\text{F} + \cdot0147\,\text{H}$, $h = -\cdot006\,\text{F} + \cdot1882\,\text{H}$, $p = -\cdot0129\,\text{F} + \cdot404\,\text{H}$, and $r = \cdot289\,\text{F} - \cdot0137\,\text{H}$, and those corrected for the tapering of the principal become $f = \cdot3367\,\text{F} + \cdot01255\,\text{H}$, $h = -\cdot011\,\text{F} + \cdot2369\,\text{H}$, $p = -\cdot01645\,\text{F} + \cdot3547\,\text{H}$, and $r = \cdot2314\,\text{F} - \cdot0075\,\text{H}$. From these corrected values of f, h, p, r are derived the following pressures on the fulcra, perpendicular to the principal, when combined with the strains in the same direction due to E as found in the second note to this Article.

Pressure perpendicular to slope of roof,		on $e =$	$\cdot47795\,\text{E} + \cdot0139\,\text{F} - \cdot00045\,\text{H} =$	864 lbs.
Ditto	ditto	on $f =$	$\cdot0694\,\text{E} + \cdot5531\,\text{F} + \cdot0297\,\text{H} =$	1189 ,,
Ditto	ditto	on $h =$	$-\cdot01945\,\text{E} - \cdot02635\,\text{F} + \cdot5674\,\text{H} =$	997 ,,
Ditto	ditto $= -\frac{p\,h}{a\,p}h$,	on $a =$	$+\cdot00075\,\text{F} - \cdot0160\,\text{H} =$	$-$ 29 ,,
		Total $=$	$\cdot5279\,\text{E} + \cdot5414\,\text{F} + \cdot58065\,\text{H} =$	3021 ,,

and a pressure on the strut fK $= {\cdot}6999\,h \times {\cdot}7231$ . . $= {\cdot}5061\,h$,
which thrusts at K with a horizontal force $= {\cdot}5061\,h \times {\cdot}7096$ $= {\cdot}3591\,h$,
and extends the queen-post K e with a force $= {\cdot}5061\,h \times {\cdot}7046$ $= {\cdot}3566\,h$.

The tension of the queen-post compresses $e\,a$ with ${\cdot}3566\,h \times 2$. $= {\cdot}7132\,h$,
and $e\,g$ with a force $= {\cdot}3566\,h \times 1{\cdot}732$ . . . . . $= {\cdot}6176\,h$,
the compression of $e\,a$ causing a horizontal push at a . . $= {\cdot}6176\,h$,
with a vertical pressure there . . . . $= {\cdot}3566\,h$.

The pressure on the straining beam at e acts on $g\,n$ with ${\cdot}6176\,h \times 1{\cdot}1547$ . . . . $= {\cdot}7132\,h$,
producing through it a horizontal thrust at n . . . $= {\cdot}6176\,h$,
with a vertical pressure there . . . . $= {\cdot}3566\,h$,
and at the same time lifts the queen-post g M with ${\cdot}3566\,h$, which causes a pressure on the strut M O $= \frac{{\cdot}3566\,h}{{\cdot}7046}$ $= {\cdot}5061\,h$,
with a thrust on the tie-beam in direction M $a = {\cdot}5061\,h \times {\cdot}7096$ $= {\cdot}3591\,h$.

The pressing up of the strut extends the rod O N with $\frac{{\cdot}5061\,h}{{\cdot}7231}$. $= {\cdot}6999\,h$,
and presses on O n with a force $= {\cdot}6999\,h \times {\cdot}9059$ . . $= {\cdot}634\,h$,
producing a horizontal thrust at $n = {\cdot}634\,h \times {\cdot}866$ . . $= {\cdot}5491\,h$,
and a vertical pressure there $= \frac{{\cdot}634\,h}{2}$ . . . . . . $= {\cdot}317\,h$.

And the tension of the rod causes a transverse strain at N $= \frac{{\cdot}6999\,h}{1{\cdot}039}$ $= {\cdot}6736\,h$,
with a horizontal push in direction N $a = {\cdot}6736\,h \times {\cdot}282$. $= {\cdot}1899\,h$,
the transverse lift raising n with ${\cdot}6736\,h \times \frac{33'}{42'}$ . . . $= {\cdot}52925\,h$,
and a with a force $= {\cdot}6736\,h \times \frac{9'}{42'}$ . . . . . . $= {\cdot}14435\,h$.

Recapitulation of strains caused by the wind.

Direct pressure on each of the small upper principals $c\,e$ and $c\,g = {\cdot}5612$ C.

Ditto on the principal $e\,a$ throughout $= {\cdot}6113\text{ C} + 1{\cdot}732\,e + 1{\cdot}4603 f + {\cdot}7132\,h$.

Ditto on ditto from f to $a = {\cdot}2717 f + {\cdot}634\,h +$ the above $= {\cdot}6113\text{ C} + 1{\cdot}732\,(e+f) + 1{\cdot}3472\,h$.

Ditto on ditto from h to $a = {\cdot}3848\,h +$ the above $= {\cdot}6113\text{ C} + 1{\cdot}732\,(e+f+h)$.

Ditto on the principal $g\,n$ throughout $= {\cdot}6113\text{ C} + 2{\cdot}3094\,e + 1{\cdot}4603 f + {\cdot}7132\,h$.

Ditto on ditto from O to $n = 2{\cdot}053\,e + 1{\cdot}2982 f + {\cdot}634\,h +$ the above $= {\cdot}6113\text{ C} + 4{\cdot}3624\,e + 2{\cdot}7585 f + 1{\cdot}3472\,h$.

Direct tension of the tie-beam at $n = {\cdot}5294\text{ C} + (2 + 1{\cdot}7779)\,e + (1{\cdot}2647 + 1{\cdot}1242)\,f + ({\cdot}6176 + {\cdot}549)\,h = {\cdot}5294\text{ C} + 3{\cdot}7779\,e + 2{\cdot}3889 f + 1{\cdot}1666\,h$.

Ditto of ditto at N $=$ the above $- ({\cdot}6151\,e + {\cdot}3889 f + {\cdot}1899\,h) = {\cdot}5294\text{ C} + 3{\cdot}1628\,e + 2f + {\cdot}9767\,h$.

Ditto of ditto at M $=$ the above $- (1{\cdot}1628\,e + {\cdot}7353 f + {\cdot}3591\,h) = {\cdot}5294\text{ C} + 2\,e + 1{\cdot}2647 f + {\cdot}6176\,h$.

Ditto of ditto at K $= {\cdot}7353 f + {\cdot}3591\,h +$ the above $= {\cdot}5294\text{ C} + 2\,(e+f) + {\cdot}9767\,h$.

Ditto of ditto at I $= 1{\cdot}0233\,h +$ the above $= {\cdot}5294\text{ C} + 2\,(e+f+h)$.

Direct tension of the tie-beam at $a =$ the above $- \{\cdot 5294\,C + 1\cdot 5\,e + (\cdot 2353 + 1\cdot 2647)\,f + (\cdot 3333 + \cdot 5491 + \cdot 6176)\,h\} = \frac{e+f+h}{2}$.

Ditto of ditto at $w = C + \cdot 73605\,E + \cdot 7293\,F + \cdot 7097\,H +$ the above $= C + \cdot 73605\,E + \cdot 7293\,F + \cdot 7097\,H + \frac{\cdot 5279\,E + \cdot 5414\,F + \cdot 5806\,H}{2} = C + E + F + H$ (Art. 23).

Vertical lift of the tie-beam at $a = (\cdot 61495 - \cdot 30565)\,C + \cdot 4598\,E + \cdot 4717\,F + \cdot 5058\,H - (\cdot 866 - \cdot 4674)\,e - (\cdot 13585 + \cdot 73015 - \cdot 2956)\,f - (\cdot 1924 + \cdot 317 + \cdot 3566 - \cdot 14435)\,h = \cdot 3093\,C + \cdot 4598\,E + \cdot 4717\,F + \cdot 5058\,H - (\cdot 3986\,e + \cdot 5704\,f + \cdot 72165\,h)$.[62]

Vertical pressure on the tie-beam at $n = (\cdot 00365 + \cdot 30565)\,C + \cdot 0027\,E + \cdot 0028\,F + \cdot 003\,H + (1\cdot 1547 + 1\cdot 0265 - 1\cdot 7138)\,e + (\cdot 73015 + \cdot 6491 - 1\cdot 0837)\,f + (\cdot 3566 + \cdot 317 - \cdot 52925)\,h = \cdot 3093\,C + \cdot 0027\,E + \cdot 0028\,F + \cdot 003\,H + \cdot 4674\,e + \cdot 2956\,f + \cdot 14435\,h$.

Transverse strain of the tie-beam at $N = 2\cdot 1812\,e + 1\cdot 3793\,f + \cdot 6736\,h$.

Direct pressure on the straining beam at e $(= \cdot 5294 - \cdot 47065) = \cdot 05875\,C + 2\,e + 1\cdot 2647\,f + \cdot 6176\,h$.

Ditto on ditto at $g = \cdot 05875\,C$.

Ditto on the upper strut $f\,K = 1\cdot 03625\,f + \cdot 5061\,h$.

Ditto on the opposite strut M O, in a reverse direction $= 1\cdot 6387\,e + 1\cdot 03625\,f + \cdot 5061\,h$.

Ditto on the lower strut $h\,I = 1\cdot 0715\,h$.

Direct tension of the queen-post $K\,e = \cdot 73015\,f + \cdot 3566\,h$.

Ditto of the opposite queen-post $g\,M$, in a reverse direction $= 1\cdot 1547\,e + \cdot 73015\,f + \cdot 3566\,h$.

Ditto of the iron rod $I\,f = \cdot 6999\,h$.

Ditto of the opposite rod O N, in a reverse direction $= 2\cdot 2663\,e + 1\cdot 4331\,f + \cdot 6999\,h$.

52. Compression of the principal rafter in direction of its length and its line of pressure on the tie-beam.

The principal rafter in this roof is not subjected to the same strain throughout its length; but of its three divisions, the higher is less compressed than the central, and the central less compressed than the lower division.

The pressure on the upper division, as caused by the weights of roof and ceiling, and possible force of wind, will be as follows:

[62] Each horizontal force tends alike to lift a and depress n with the lever of its height above the line $a\,n$, opposed by the lever $a\,n$ (Art. 22). These products are for $C = \frac{C\,d \times w\,d}{a\,n} = \cdot 3093\,C$, for $E = \frac{E\,q \times w\,o}{a\,n} = \cdot 244\,E$, for $F = \frac{F\,v \times w\,s}{a\,n} = \cdot 1684\,F$, for $H = \frac{H\,y \times w\,x}{a\,n} = \cdot 0928\,H$, and the whole vertical strain at a or at n is their sum, or $\cdot 3093\,C + \cdot 244\,E + \cdot 1684\,F + \cdot 0928\,H = 1315$ lbs., which agrees with the sum of the strains enumerated above, whether for the lift at a or pressure at n, e being $= \cdot 4962\,E + \cdot 0325\,F = 931$ lbs., $f = \cdot 0317\,E + \cdot 5089\,F + \cdot 0396\,H = 1061$ lbs., and $h = \cdot 54105\,H = 1029$ lbs. But if we substitute the more accurate values found in the preceding note of $e = 864$ lbs., $f = 1189$ lbs., $h = 997$ lbs., and $a = -29$ lbs. (in which case the lift at a above enumerated must be augmented by $\cdot 866\,a = 25$ lbs.), the strain at a or at n becomes 1317 lbs., showing an error of 2 lbs. which takes rise in the correction for the tapering of the timber.

Weight of roof on C = 1585 lbs. (Art. 45) × 1 (Art. 39)		= 1585 lbs.
Ditto	on e = 1280 lbs. (note, Art. 47[63]) + 193 lbs. (Art. 48) = 1473 lbs. × 2 (Art. 47)	= 2946 ,,
Ditto	on f = 2332 lbs. (note, Art. 47) + 87 lbs. (Art. 48) = 2419 lbs. × 1·2646 (Art. 47)	= 3059 ,,
Ditto	on h = 2580 lbs. (note, Art. 47) + 77·5 lbs. (Art. 48) = 2657·5 lbs. × ·6176 (Art. 47)	= 1641 ,,
Ditto	on I = 77·5 lbs. (Art. 48) × 1·0588 (Art. 48) . .	= 82 ,,
	Pressure of roof	= 9313 ,,

Weight of ceiling on K = 1130 lbs. (Art. 49) × 2 (Art. 47)		= 2260 lbs.
Ditto	on I = 1201·75 (Art. 49) × 1·0588 (Art. 48) . .	= 1272 ,,
	Pressure of ceiling	= 3532 ,,

Horizontal force of wind on C = 1300 lbs. (Art. 50) × ·6113 (Art. 51) .		= 795 lbs.
Force of wind perpendicular to roof on e = 864 lbs. (note, Art. 51) × 2·3094[64] (Art. 51)		= 1995 ,,
Ditto ditto	on f = 1189 lbs. (note, Art. 51) × 1·4603 (Art. 51)	= 1736 ,,
Ditto ditto	on h = 997 lbs. (note, Art. 51) × ·7132 (Art. 51) .	= 711 ,,
	Possible pressure of wind . .	= 5237 ,,

Total direct compression of the upper division of the principal rafter = 9313 lbs. + 3532 lbs. + 5237 lbs. = 18082 lbs.

The pressure on the central division of the principal rafter will be, from the weight of roof on C and e, as in upper division . .		= 4531 lbs.
Ditto	on f = 2419 lbs. × 2 (Art. 47)	= 4838 ,,
Ditto	on h = 2657·5 lbs. × 1·1667 (Art. 47)	= 3100·5 ,,
Ditto	on I = 77·5 lbs. × 2 (Art. 48)	= 155 ,,
	Pressure of roof	= 12624·5 ,,

Weight of ceiling on K presses as on upper division, with force . . .		= 2260 lbs.
Ditto	on I = 1201·75 lbs. (Art. 49) × 2 (Art. 48) . . .	= 2403·5 ,,
	Pressure of ceiling	= 4663·5 ,,

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[63] These pressures on e, f, h, I consider the nearest approximations to truth.

[64] The pressures of the wind on the principal rafter $g\,n$, fig. 21, being greater than those on the opposite principal $e\,a$, must necessarily be allowed for in preference to the latter. See Art. 51, *Recapitulation.'*

Force of wind on C causes pressure as on upper division	. . . .	= 795 lbs.
Ditto	on e = 864 lbs. perpendicular to roof (note, Art. 51) × 4·3624 (Art. 51)	= 3769 ,,
Ditto	on f = 1189 lbs. perpendicular to roof (note, Art. 51) × 2·7585 (Art. 51)	= 3280 ,,
Ditto	on h = 997 lbs. perpendicular to roof (note, Art. 51) × 1·3472 (Art. 51)	= 1343 ,,
	Possible pressure of wind . .	= 9187 ,,

Total direct compression of the middle division of the principal rafter = 12624·5 lbs. + 4663·5 lbs. + 9187 lbs. = 26475 lbs.

The pressure on the lower division of the principal rafter will be from the weight of the roof on C, e, f, I as on the central division		= 9524 lbs.
Ditto	on h = 2657·5 lbs. × 2 (Art. 47)	= 5315 ,,
	Pressure of roof . . .	= 14839 ,, [65]
Pressure of ceiling as on central division	. . . . . .	= 4663·5 ,, [66]
Possible pressure of wind as on central division	. . . . . .	= 9187 ,,
Total direct compression of the lower division of the principal rafter	. .	= 28689·5 ,,

With respect to the line of pressure of the principal rafter on the tie-beam, it will be very nearly in the direction of the axis of the former; for it is compounded of two lines, the one representing the sum of the direct or axial strains, and the other the sum of the vertical strains, conveyed through the principal to its point of intersection with the tie-beam a. Now the former of

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[65] Or C = 1585 lbs. (Art. 45) . . . . . = 1585 lbs.
+ 2 E = 2163 ,, × 2 (idem) . . . . . = 4326 ,,
+ 2 F = 1966 ,, × 2 (idem) . . . . . = 3932 ,,
+ 2 H = 2146 ,, × 2 (idem) . . . . . = 4292 ,,
+ Weight of truss = 1017 lbs. (Art. 48) . . . = 1017 ,,
15152 ,,
Deduct parts of truss resting on wall only = 73·5 lbs. (Art. 48) × 2 . . . . . = 147
Ditto part of H which presses vertically on a = 83 lbs. (note, Art. 47) × 2 . . . = 166
313 ,,
Weight of the roof causes a direct pressure of the principal on a = 14839 ,, (See Arts. 39 and 46, last paragraph.)

[66] Or 2 K = 1130 lbs. (Art. 49) × 2 . . . . . = 2260 lbs.
+ 2 I = 1201·75 ,, (idem) × 2 . . . . . = 2403·5 ,,
Weight of ceiling causes a direct pressure of principal on a . . = 4663·5 ,, (Arts. 39, 46.)

these sums (exclusive of the possible stress of wind) is 14839 lbs. + 4663·5 lbs. = 19502·5 lbs.; while the latter is only 83 lbs. (note, Art. 47) + 23·5 lbs. (Art. 48) = 106·5 lbs.; and the line of pressure thus compounded will form an angle of 30° 21′ with the horizon, being only 21 minutes larger than the angle of the principal therewith.

53. Transverse section of the principal rafter; Proportions of its breadth and depth.

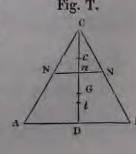
If a short beam be compressed with sufficient force in direction of its length, it will be split or crushed; but if its length be more than seven or eight times its thickness, it will bend, in which case the action of the compressing force is assumed to be similar to that of a transverse force acting on the side of the beam opposite to the deflection. The only transverse section that offers an equal resistance on every side is the circle; but as the beams of a truss must generally for convenience be of a rectangular section, it is important to ascertain what are the stiffest proportions of that form. According to Galileo's theory the transverse strength of a square beam in direction of its side is to the same in direction of its diagonal as 1 to the square root of 2,[67] and by Leibnitz's theory the proportions would be $\frac{4}{5}$ to the square root of 2; but Mr. Barlow, in his excellent 'Essay on the Strength and Stress of Timber,' after stating the results of those theories, adds that by experiment the strength in direction of the side is the greater of the two. From the few experiments detailed in his book, and the application of the theory as therein explained of compressed and extended areas divided by a neutral axis,[68] we shall probably

[67] Hutton's 'Mathematics,' vol. ii. Prop. 48, page 206, Art. 243.

[68] The general correctness of this theory is not sought to be maintained, for it fails in its application to other less elastic materials. It has however been so carefully and ingeniously adjusted to actual experiments on timber, that its results when applied to that material in or near the breaking state may be relied on. The following instances, taken from experiments by Mr. G. Rennie (Barlow's Essay, Appendix, Art. 17), exhibit at the same time in a striking manner how inapplicable this theory is to cast iron.

Experiments Nos. 11 and 13. Triangular bar equilateral, supported at each end, base extended. Length $= \begin{cases} 32'' \\ 16'' \end{cases}$, breaking weight $= \begin{cases} 1437 \text{ lbs.} \\ 3059 \text{ ,,} \end{cases}$, weight of bar $= \begin{cases} 9 \text{ lbs. } 11 \text{ oz.} \\ 4 \text{ ,, } 13\tfrac{1}{2} \text{ ,,} \end{cases}$ Transverse section = 1 square inch = A B C (see figure). Whence $w = 1486$ lbs. average breaking weight for 32 inches length, and $DC = \sqrt[4]{3}$.

Fig. T.



Make $nC = y$, then $nc = \frac{y}{3}$ and $nG = \frac{2}{3}\sqrt[4]{3} - y$ (Barlow's Essay, p. 181, Art. 130), and by proportion, attain as close an approximation to the most advantageous proportions for the sides of a rectangular beam directly compressed, as our limited knowledge of facts connected with the subject will supply. No accurate decision can indeed be arrived at without the aid of further experiment,[69] but when we find the

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$$D C^2 : n C^2 :: A B C : N C N,$$

or, $\sqrt{3} \ : y^2 \ :: 1 : \frac{y^2}{\sqrt{3}} =$ area N C N and $1 - \frac{y^2}{\sqrt{3}} =$ area A N N B.

Fig. S.

By property of centres of gravity G, c, and t, $nt \times ANNB = nc \times NCN + nG \times ABC$.

By formula $8 f a x = l w$ (Barlow's Essay, Art. 129) $a x$, or $nt \times ANNB = \frac{lw}{8f} = \frac{32 \times 1486}{8 \times 18337} = \cdot 324133$.

Whence the equation $\frac{y}{3} \times \frac{y^2}{\sqrt{3}} + \frac{2}{3} \sqrt[4]{3} - y = \cdot 3241533$, giving $y = \cdot 594$.

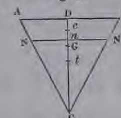
Also $NCN = \cdot 2037$, $ANNB = \cdot 7963$, $nD = \cdot 722$ and $nt = \cdot 407$.

By formula $w \times nt = w' \times nc$ (Barlow's Essay, Art. 120), or $f \times ANNB \times nt = F \times NCN \times nc$, we obtain the value of resistance to compression per square inch, $F = 147374$ lbs.

N. B. f. The value of direct cohesion per square inch $= 18337$ lbs. (Barlow's Essay, Appendix, Art. 20). N N. Neutral axis dividing the areas of tension and compression.

Experiments Nos. 12 and 14. Triangular bar equilateral, supported at each end, edge extended. Length $\left\{\begin{matrix} 32'' \\ 16'' \end{matrix}\right.$, weight of bar $\left\{\begin{matrix} 9 \text{ lbs. } 7 \text{ oz.} \\ 4 \ \text{,,} \ 11\frac{1}{2} \ \text{,,} \end{matrix}\right.$, breaking weight $\left\{\begin{matrix} 840 \text{ lbs.} \\ 1656 \ \text{,,} \end{matrix}\right.$. Transverse section $= 1$ square inch, A B C (see figure). Hence $w = 837$ lbs. average breaking weight for 32 inches length and $DC = \sqrt[4]{3}$.

Fig. R.



Make $n C = y$, then $nt = \frac{y}{3}$, and by proportion,

$$D C^2 : n C^2 :: A B C : N C N,$$

or $\sqrt{3} \ : \ y^2 \ :: \ 1 : \frac{y^2}{\sqrt{3}} =$ area N C N.

By formula $8 f a x = l w$, we have $a x$ or $nt \times NCN = \frac{lw}{8f} = \cdot 18258$, or $\frac{y^2}{\sqrt{3}} \times \frac{y}{3} = \cdot 18258$, whence $y = \cdot 9826$, also $nD = \cdot 3335$, $nG = \cdot 1052$, $nt = \cdot 3275$, $NCN = \cdot 5574$, and $ANNB = \cdot 4426$. To find nc, by property of centres of gravity, $nt \times NCN - nc \times ANNB = nG \times ABC$, which gives $nc = \cdot 1748$.

Now by formula $f \times NCN \times nt = F \times ANNB \times nc$, we find the value of resistance to compression per square inch $F = 43267$ lbs.

We see that the foregoing application of this theory has given us two values for F, differing so widely as 147374 lbs., and 43267 lbs.; and though the results of its application to rectangular bars do not exhibit so great a discrepancy, they are far from agreeing either with one another or with the values above found.

Cast iron bar, 1 inch square, with side extended (Experiments 1, 2, 3) gives F . $= 90280$ lbs.
Ditto 4 inches $\times \frac{1}{4}$ inch, with smaller side extended (Experiment 10) gives F $= 68597$,,

[69] The few experiments given by Mr. Barlow exhibit only the ultimate deflection of beams and the breaking weight, but the important desideratum in carpentry is their comparative strength while

proportions of 10 to 6 and 10 to 7 recommended for the sides of a rectangular post by a standard authority, and almost universally adopted, it seems advisable at once to arrest so grave an error, and to show that these proportions are deduced from false principles,—are at variance with experiments on the final strength of timber (the only experiments, I believe, as yet furnished for our guidance), and with the theory adopted by Mr. Barlow as giving coincident results.

The following are extracts from Tredgold's 'Carpentry,' the authority to which I have referred in the preceding paragraph. Art. 105. "When a square beam is strained in the direction of its diagonal, its strength is less in the proportion of 0·7071 to 1." Art. 119. "The stiffest rectangular post is that in which the greater side is to the less as 10 is to 6." Art. 187. "In order that this beam (the straining beam) may be the strongest possible, its depth should be to its thickness as 10 to 7."

The source whence these conclusions were derived does not appear in the 'Essay on Carpentry,' but is to be found in the 'Essay on Cast Iron' by the same author, who gives therein (2nd edition of 1824, Art. 80) a demonstration, from which is drawn the following consequence: "The strength of a square beam when the force is parallel to its side, is to the strength of the same beam when the force is in the direction of its diagonal as $1 : \sqrt{2}$ or as 10 is to 7, nearly;" and in laying down the principles on which his demonstration is founded, Mr. Tredgold remarks ('Essay on Cast Iron,' Art. 69),—"The doctrine of the strength of materials as given in this work rests upon three first principles, and these are abundantly proved by experiment;" and (Art. 72)—"The truth of these premises being admitted, every rule that is herein grounded upon them may be considered as firmly established as the properties of geometrical figures."

But if the truth of the premises be not established, the rules therein grounded will necessarily partake of their uncertainty, and the naked assertion of the author, that the principles announced in his Essay are abundantly proved by experiment, neither carries conviction, nor ought it (however great the authority of Mr. Tredgold's name) to be received without due examination.

elasticity is unimpaired. We have no authority for assuming that the same law governs the first slight deflection and the deflection immediately preceding fracture. Some careful experiments on the first small deflections are those required, and would at once decide what are the stiffest proportions for a rectangular post.

Now I shall at once admit that the first and second of the three principles propounded in the Essay appear to me unobjectionable, and that I have discovered no error in the demonstration through which the consequence above quoted regarding the strength of a square beam is arrived at. It is to the third principle that I request the reader's attention, being altogether incredulous of its truth. The experiments so abundantly proving it are not described, nor am I aware that any have been made with the intention of bearing directly on this subject; but if the experiments which we possess on the final strength of materials could be admitted as analogous to those on their strength with elasticity unimpaired, they would lead to an opposite result.

Mr. Tredgold, in his 'Essay on Cast Iron,' Art. 71, thus announces his third principle. "That while the force is within the elastic power of the material, bodies resist extension and compression with equal forces;" and in Art. 75, he further and more definitely explains his meaning to be, that "Portions of the same matter of equal area resist extension or compression with equal forces," adding in a note, "But when the strain exceeds the elastic force of a body, the resistance to compression exceeds the resistance to tension; consequently the effect of the filaments must be $\frac{Aa.S+eA.S'}{Ba}$. Now the difference between S and S′ will be constantly increasing till fracture takes place, the area of the compressed part being constantly increasing and that of the extended part diminishing." (S signifying the resistance of a filament to tension, and S′ its resistance to compression.)

Now the addition in the note, be it observed, is not a corollary from the third principle, but appears to be a simple conjecture, and is not only unfounded on it, but contrary to fact, even if the principle were true.[70] And

[70] The note above quoted refers to a bar of cast iron subjected to a transverse strain. The resistance of a filament of cast iron to rending asunder is shown from experiment to be not more than one-seventh of its resistance to crushing, and as however rapidly the destruction of elasticity may proceed, we must assume that at each moment the resistances to the opposing powers of tension and compression are equal, because those powers are throughout equal (very nearly); therefore must the number of filaments extended (or the area of the extended part) be the greater to compensate for their comparative want of strength as they approach the breaking point, and establish their equilibrium with the compressed filaments, the latter offering at that crisis seven times the resistance of a like bundle of extended filaments. In other words, admitting the postulate that on the first application of the force the areas of the extended and compressed filaments are equal, the area of the extended, and not of the compressed, as stated by Tredgold, will be constantly increasing till fracture.

for this reason I have quoted it, to justify the doubts I entertain of his accuracy in other points.

The following are deductions regarding the resistance of cast iron to crushing and tearing asunder, made from an examination and comparison of the experiments by G. Rennie, Esq. (Barlow's Essay, Appendix, Art. 27, and Tredgold's Essay, Art. 64.)

1st. That the resistance of a cube of $\frac{1}{8}$th of an inch to crushing was not less than 1416 lbs., being at the rate of 90624 lbs. per square inch.

2nd. That the mean resistance of a cube of $\frac{1}{4}$ of an inch to crushing was 8679 lbs., or at the rate of 138864 lbs. per square inch (from the three sorts of iron experimented on by Mr. Rennie, and the soft grey metal tried by Mr. Reynolds).

3rd. That the resistances of columns less than an inch long, whose bases were respectively $\frac{1}{4}$th and $\frac{1}{8}$th of an inch square were, the lengths being equal, as 545745 to 506680, or as 1·08 to 1 nearly.

4th. That in columns of $\frac{1}{4}$ of an inch square base, and less than an inch high, an increase of $\frac{1}{8}$th of an inch in the height of the column diminished its resistance to crushing by about $\frac{1}{15}$th of the resistance of the cube of its base, and that in columns of $\frac{1}{8}$th of an inch square, and less than 1 inch high, an increase of $\frac{1}{8}$th inch in the height diminished the resistance by about $\frac{1}{19}$th of that of the cube.

The mean resistance to tearing asunder was ascertained with greater certainty to be about (18337 ?) 18342 lbs. per square inch (Barlow's Essay, Appendix, Art. 20), and comparing this with the mean found above for resistance to crushing in bars of the same size, namely, 138864 lbs., the proportions of the two are as 1 to 7·57.

In the 'Essay on Cast Iron,' Art. 64, is the following remark: "It does not appear within the limits of these experiments that an increase of length had any sensible effect on the result." As this remark is at variance with one of the preceding deductions (No. 4), I subjoin my analysis of the experiments, showing how that deduction was made.

Side of base.	Height.	Mean crushing force = lbs.	Corrected mean = lbs.	Weights decreasing by $708\frac{1}{3}$ lbs., being $\frac{1}{15}$th of the weight which crushes the cube of the base.
				lbs.
$\frac{1}{4}$ inch.	$\frac{2}{8}$ inch.	Of 4 experiments . = 9773	(A softer iron, rejected.)	
Ditto.	Ditto.	Of 9 experts. in 2 sets = 10625	As before . . . = 10625	10625
Ditto.	$\frac{3}{8}$ inch.	Of 2 experiments . = 9167	Of $\frac{2}{8}, \frac{3}{8}, \frac{4}{8}$ . . = 9830	9917
Ditto.	$\frac{4}{8}$ inch.	Of 4 experiments . = 9698	Of $\frac{2}{8}$ to $\frac{6}{8}$ . . . = 9247	9208
Ditto.	$\frac{5}{8}$ inch.	Of 2 experiments . = 8615	Of all . . . . = 8476	8500
Ditto.	$\frac{6}{8}$ inch.	Of 2 experiments . = 8129	Of $\frac{4}{8}$ to $\frac{8}{8}$ . . . = 7908	7792
Ditto.	$\frac{7}{8}$ inch.	Of 2 experiments . = 6724	Of $\frac{6}{8}, \frac{7}{8}, \frac{8}{8}$ . . . = 7076	7083
Ditto.	$\frac{8}{8}$ inch.	Of 2 experiments . = 6375	As before . . . = 6375	6375
				Decreasing by $120\frac{1}{2}$ lbs., being $\frac{1}{19}$th of the weight which crushes the cube.
$\frac{1}{8}$ inch.	$\frac{1}{8}$ inch.	Of 3 experiments . = 1440	(A very soft iron, rejected.)	2290
Ditto.	$\frac{2}{8}$ inch.	Of 2 experiments . = 2116	As before . . . = 2116	2169
Ditto.	$\frac{3}{8}$ inch.	Of 2 experiments . = 2363	Of $\frac{2}{8}, \frac{3}{8}, \frac{4}{8}$ . . . = 2161	2049
Ditto.	$\frac{4}{8}$ inch.	Of 2 experiments . = 2005	Of $\frac{2}{8}$ to $\frac{6}{8}$ . . . = 1927	1928
Ditto.	$\frac{5}{8}$ inch.	Of 2 experiments . = 1407	Of all . . . . = 1809	1808
Ditto.	$\frac{6}{8}$ inch.	Of 2 experiments . = 1743	Of $\frac{4}{8}$ to $\frac{8}{8}$ . . . = 1638	1687
Ditto.	$\frac{7}{8}$ inch.	Of 2 experiments . = 1594	Of $\frac{6}{8}, \frac{7}{8}, \frac{8}{8}$ . . . = 1592	1567
Ditto.	$\frac{8}{8}$ inch.	Of 2 experiments . = 1439	As before . . . = 1439	1446

To return to the principle itself, which relates solely to the resistance of bodies while their elasticity is unimpaired; I have already stated that I am not acquainted with any series of experiments instituted to decide on the resistances of bodies with unimpaired elasticity, to compression and extension respectively. The well-known facts, however, that in most kinds of timber a force which crushes will not permanently extend, and that in cast iron a force which rends asunder will not crush, are, I think, decisive as to the inequality of these resistances in different bodies, even to "forces within the elastic power of the material." For in the instance of timber, though the elasticity be exceeded when a certain force is applied to crush, it is unimpaired by the application of the same force to extend the timber, and in cast iron the effect is just the reverse.

Having shown that this principle is probably false, and that the proportions deduced from it as most advantageous for a rectangular beam in a state of direct compression, cannot therefore be maintained; let us proceed to examine the few experiments given in Mr. Barlow's Essay, on the comparative transverse strength of square beams, in directions of the side or the diagonal.

The comparative experiments given by Mr. Barlow (Essay, Arts. 78, 81, 82, 83) are with fir, ash, beech, and elm, and the medium result on these four kinds of wood is, that the transverse strength of a square beam to resist fracture with side parallel to the force causing it, is to the strength when the force is in the direction of the diagonal as 1 is to ·958, namely,

The strength of fir is	(mean of 3 trials of each position)	as $396\frac{1}{3}$ lbs.	to $388\frac{1}{3}$ lbs.,	or as 1 :	·979815
Ditto of ash is	(mean of 2 trials of each position)	as $433\frac{1}{2}$,,	to 390 ,,	or as 1 :	·899654
Ditto of beech is	(mean of 3 on side and 2 on diagonal)	as 401 ,,	to 382 ,,	or as 1 :	·952618
Ditto of elm is	(mean of 3 trials of each position)	as 246 ,,	to 246 ,,	or as 1 :	1
The mean proportion is as	. . . . .			4 :	3·832087,

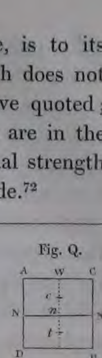
or as 1 to ·958.

If we now compute the comparative strength of a beam of teak in these two positions by the formula given for finding the transverse strength of any beam (Barlow's Essay, Tredgold's practical application, Art. 154), $\frac{2C \times T \times gn}{l} = W$, then C and l being the same in both positions, the strengths will be as $T \times gn$, or as the respective areas of tension multiplied by the distances of their centres of gravity from the neutral axis, and these proportions in teak will be as 1 to ·9538.[71] Therefore, according to Mr. Barlow's theory, the transverse

[71] Let A C B D be the transverse section of a beam of teak, 1 inch square, supported at both ends

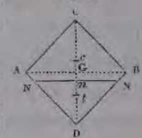
strength of a square beam of teak with side parallel to the force, is to its strength with diagonal in direction of the force as 1 to ·9538, which does not much differ from the results of the experiments on other woods above quoted; and the strongest rectangular post of teak will be that whose sides are in the proportion of 1·0926 to 1, or of 12 to 11, very nearly, its diagonal strength being in that case equal to its strength in direction of its smallest side.[72]

Fig. Q.



and acted on by a breaking weight at W. Draw N N to represent the neutral axis, making C N or A N = ·6 (Barlow's Essay, Art. 143, Table). Then the product of the area of tension D N N B into the distance nt of its centre of gravity from the neutral axis, will be to the product of the area of compression A N N C into the distance nc of its centre of gravity from the neutral axis as $\cdot 4 \times \cdot 2$ is to $\cdot 6 \times \cdot 3$, or as 4 to 9.

Fig. 5.



Let the same beam be now acted on at C by the same weight whilst its diagonal C D is vertical, D N N being the area of tension, t its centre of gravity, A N N B C the area of compression, c its centre of gravity, and G the centre of gravity of A C B D.

It has been just shown that the ratio of the product of the area of tension into the distance of its centre of gravity from the neutral axis, to the product of the area of compression into the distance of its centre of gravity from the neutral axis, is in teak, 4 to 9.

Therefore $nc \times \mathrm{ANNBC}$ . . . . $= \frac{9}{4} nt \times \mathrm{DNN}$;

And by property of the centre of gravity (Hutton's 'Mathematics,' vol. ii. Prop. 41, Art. 220), $nc \times \mathrm{ANNBC}$ . . $\Big\} = nG \times \mathrm{ACBD} + nt \times \mathrm{DNN}$.

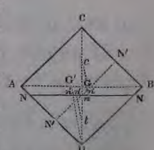
Whence the equation $\frac{9}{4} nt \times \mathrm{DNN}$ . . . . . $= nG \times \mathrm{ACBD} + nt \times \mathrm{DNN}$.

Giving $nt = \cdot 203909$, and $nt \times \mathrm{DNN} = \cdot 07630577$.

But in the first figure $nt \times \mathrm{DNNB} = \cdot 2 \times \cdot 4 = \cdot 08$.

The strengths therefore with side parallel to, or with diagonal in direction of, the force, are as ·08 to ·07630577, or as 1 to ·953822.

[72] To find the transverse section of a rectangular beam, the ultimate strengths of which in direction of its diagonal and of its smallest side, shall be equal.



Let A C B D be a cross section of the beam acted on by a breaking weight at C. Call D B = x, A D being = 1. Draw the neutral axis N N parallel to A B (which it must be in order that the line of pressure C D may equally divide the areas of tension and compression). Mark t, c, and G, the respective centres of gravity of DNN, of ANNBC, and of ACBD, and draw $n't$, $n'c$, and D G′ perpendicular to NN. Draw also N′N′ as the neutral axis if A D were vertical, parallel to and ·6 distant from the upper side A C. (See the first figure, preceding note.)

By ratio of areas of tension and compression into respective distances of their centres of gravity from the neutral axis (see preceding note) $n'c \times \mathrm{ANNBC} = \frac{9}{4} n't \times \mathrm{DNN}$, or by substitution of proportionals . . . . . $nc \times \mathrm{ANNBC} = \frac{9}{4} nt \times \mathrm{DNN}$,

and by property of centre of gravity $nc \times \mathrm{ANNBC} = nG \times \mathrm{ACBD} + nt \times \mathrm{DNN}$.

The strongest section of a rectangular teak post to resist at the same time absolute transverse fractures, both diagonal and lateral, has been thus determined; and in the absence of experiments enabling us to ascertain the stiffest section, or that which would offer the greatest resistance to bending, we must be content to adopt the former; nor is it improbable that the two may be found hereafter to approximate closely.

54. Scantlings of the principal rafters.

When a post is compressed at its ends, the strain will seldom take place exactly in direction of its axis, and as the determination of the strain when it does coincide with the axis is attended with difficulties which have not been surmounted,[73] and the coincidence can never be reckoned on, let us proceed to consider the case when the direction of the straining force and the axis do not coincide. For this case the following formula is given by Tredgold ('Essay on

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Whence the equation $n t \times \mathrm{DNN} = \frac{4}{5} n \mathrm{G} \times \mathrm{ACBD}$, or by substitution of proportionals $n' t \times \mathrm{DNN} = \frac{4}{5} n' \mathrm{G}' \times \mathrm{ACBD}$, and by terms of the proposition $n' t \times \mathrm{DNN} = \frac{\mathrm{DN}'}{2} \times \mathrm{DN}'\mathrm{N}'\mathrm{B}$.

Whence the equation $\frac{4}{5} n'\mathrm{G}' \times \mathrm{ACBD} = \frac{\mathrm{DN}'}{2} \times \mathrm{DN}'\mathrm{N}'\mathrm{B}$, or $\frac{4}{5} n'\mathrm{G}' x = \cdot 2 \times \cdot 4\, x$, giving $n'\mathrm{G}' = \cdot 1$.

Also $\mathrm{DG}'^2 : \mathrm{D}n'^2 :: \mathrm{DAB} : \mathrm{DNN}$, or $(3\, n' t + \cdot 1)^2 : (3\, n' t)^2 :: \frac{x}{2} : \frac{(3\, n' t)^2}{(3\, n' t + \cdot 1)^2} \times \frac{x}{2} = \mathrm{DNN}$.

And by substituting these values of $n'\mathrm{G}$ and DNN in the equation $n' t \times \mathrm{DNN} = \frac{4}{5} n' \mathrm{G}' \times \mathrm{ACBD}$, we have $n' t \times \frac{(3\, n' t)^2}{(3 n' t + \cdot 1)^2} \times \frac{x}{2} = \cdot 08\, x$, giving $n' t = \cdot 21378433$ and $\mathrm{DG}' = 3 n' t + n' \mathrm{G}' = \cdot 74135299$.

Now, $\mathrm{ACBD} = \mathrm{DG}' \times \mathrm{AB} = \mathrm{DG}' \times \sqrt{\mathrm{AD}^2 + \mathrm{DB}^2}$.

Or, $1 \times x = \cdot 74135299 \times \sqrt{1^2 + x^2}$.

Whence, x is found $= 1 \cdot 0926 = \mathrm{DB}$.

[73] The formula $f = \frac{2 \cdot 4675\, \mathrm{E}\, a\, d^3}{l^2}$ derived from an equation in Dr. Young's 'Natural Philosophy,' and from another in Mr. Barlow's Essay (Tredgold's application, Art. 163, Prob. 7), was framed to determine the dimensions of a pillar to bear a given stress in the direction of its axis without sensible curvature. It affords a curious illustration of the small value of scientific theories not carefully tested by experiment. We do not approach to a correct finding by this formula till the length of the column be about fifty times its thickness. A square pillar of oak with a length equal to eight times its side would, according to this formula, bear four times the weight which is known to crush that material, and with a length of twelve times its side, twice the crushing weight; while with a length of twenty-four times its side, the load assigned by this rule would certainly break the pillar. If we go further back and apply the formula to a cube of oak (and there is no limit to the length of the column in the problem), it gives for the load 244 times the crushing weight.

Cast Iron,' Art. 241, and Barlow's Essay, practical application, Art. 153, Prob. 8), namely, $\frac{C a d^2}{d + 6c + \frac{6 l^2}{d U}} = W$.[74] The rationale of this form seems to be, that the post is supposed to be bent to its last possibility of deflection before breaking, and that the pressure having been thus transferred from the axis to the edge, or nearly so, according to the nature of the material,[75] acts in direction of the smaller sides. This state of the pillar is nearly the most unfavourable that can be devised, and if we attend also to the caution, that "in practice the weight given by the rule be divided by 4,"[76] there can be no danger of the slightest flexure taking place, and the utmost desirable security will be attained.

In the truss of which we are now treating, fig. 20, the whole length of the principal rafter from a to e is $= 17' \times 1{\cdot}1547 = 19{\cdot}63$ feet,[77] but it is practically divided into three lengths and made immoveable at the points h and f by the purlins and struts there confining it. These three lengths are $a\,h = 6'{\cdot}0622$ or $72''{\cdot}75$, $h f = 6'{\cdot}3509$ or $76''{\cdot}21$, and $f e = 7'{\cdot}2169$ or $86''{\cdot}6$. The thickness of the principal is limited by that of the tie-beam, which cannot with advantage be made more than 5 inches in this truss. Applying then the formula $\frac{C a d^2}{d + 6c + \frac{6 l^2}{d U}} = 4\,W$, or $\frac{\left(d + 6c + \frac{6 l}{d U}\right) \times 4\,W}{C d^2} = a$, we have the mean breadth of $a\,h = \frac{\left(5'' + 10'' + \frac{6 \times 72''{\cdot}75^2}{5'' \times 818}\right) \times 4 \times 28689{\cdot}5 \text{ lbs.}}{15550 \text{ lbs.} \times 5''^2} = 6{\cdot}7199$ inches, the

[74] C. Force of direct cohesion on a square inch $= 15550$ lbs. in teak (Barlow's Essay, Table, Art. 163).

U. Ultimate deflection on ditto $=$ 818 ,, in ditto (idem).

a. Breadth of post in inches (here meaning the larger side).

d. Depth of ditto in ditto (here meaning the smaller side).

l. Length of ditto in ditto.

c. Deviation of strain from the axis (here to be taken as $\frac{1}{3}$rd depth, Barlow's Essay, practical application, Art. 153, Prob. 8).

W. Breaking weight.

[75] In Tredgold's 'Essay on Cast Iron,' Art. 235, the deviation of the strain from the axis is directed to be taken at half the thickness, which is the same as considering it to act on the plane of one surface. In timber the same author only reckons on a deviation of one-third of the thickness (see preceding note), probably on account of the more yielding nature of the material.

[76] Which should be done by substituting 4 W for W in the equation.

[77] This is the extreme length from the ends of the tenons, which are supposed to coincide with the intersections of the axis of the principal with those of the tie and straining beams.

mean breadth of $hf = \dfrac{\left(5'' + 10'' + \frac{6 \times 76''{\cdot}21^2}{5'' \times 818}\right) \times 4 \times 26475 \text{ lbs.}}{15550 \text{ lbs.} \times 5''^2} = 6{\cdot}4072$ inches, and the mean breadth of $f\,e$ would be $= \dfrac{\left(5'' + 10'' + \frac{6 \times 86''{\cdot}6^2}{5'' \times 818}\right) \times 4 \times 18082 \text{ lbs.}}{15550 \text{ lbs.} \times 5''^2}$ $= 4{\cdot}8377$ inches; but as a in this last instance becomes the smaller side, it must change places with d in the equation, and its value thus comes out $= 4{\cdot}91184$ inches.

And the actual mean breadths in the truss, fig. 20, are, of $a\,h = 6''{\cdot}90625$, of $h\,f = 6''{\cdot}1$, and of $f\,e = 5''{\cdot}21875$.

55. But it may be objected to the foregoing formula that it is deduced in part from principles the correctness of which is doubtful, and this leads to the inquiry—Have not experiments on the direct compression of timber been recorded, and to what results do they lead? Many of the valuable experiments made by Lamandè and Girard are given in Mr. Tredgold's and Mr. Barlow's Essays,[78] but have hitherto been passed over as too irregular in their effects to afford any just or useful deductions. A careful collation of these experiments has led me to a higher appreciation of their importance, and to the construction of a Table from which may be found very readily the actual average resistance of an oak beam both to bending and to fracture from a force pressing in direction of its length; and as teak resembles oak very nearly in the situation of its neutral axis,[79] the Table may be used for that timber also, without risk of material error.

There are altogether fifty-seven of these experiments recorded in Tredgold's and Barlow's Essays, namely, thirty-six by Lamandè and twenty-one by Girard. Three of those by Girard are given only in the selection made by Tredgold, and after the others. The breaking weight for two of the three is not in his Table, and as they show a great discrepancy from the other pieces in the unusual smallness of the weight causing flexure, and were perhaps selected on that account, I have thought it advisable to take only those of Girard's experiments which are to be found also in Barlow's Essay, eighteen in number.[80] We shall presently see that though the separate experiments display, as might be expected, considerable irregularity, particularly in the weights causing flexure, yet the means of the respective sets by Lamandè and Girard agree very

78 Tredgold's 'Carpentry,' Art. 123, Table XI., and Barlow's Essay, Art. 154, Table IV.

79 Barlow's Essay, Art. 143, Table of data.

80 Two or three obvious errors in the given figures have been corrected in calculating.

closely. The Table is constructed in the following manner. The proportion of the length to the smaller side is found for each piece, and the weight divided by the number of square inches in the transverse section.

GIRARD'S EXPERIMENTS.

Number of trials.	Length in terms of smallest side.	No. of lbs. per square inch causing first flexure.	No. of lbs. per square inch causing fracture.	Number of trials.	Length in terms of smallest side.	No. of lbs. per square inch causing first flexure.	No. of lbs. per square inch causing fracture.
1	14·650	1863	2715	1	20·205	1211	2965
1	14·896	1946	3347	1	21·011	996	3290
1	17·302	2031	3709	1	21·887	1520	2906
1	17·689	1603	3284	1	22·296	1328	2250
1	18·008	1223	3800	1	22·395	1532	2531
1	18·381	1741	4728	1	24·509	977	3464
1	19·196	1532	3473	1	24·518	1229	2349
1	19·196	1400	2876	1	25·595	1060	2771
1	19·201	796	2475	1	26·632	1229	2469
9	158·519	14135	30407	9	209·048	*11144	24995
Average	17·6132+	1570·55+	3378·55+	Average	23·2275+	*1238·22+	2777·22+

LAMANDÈ'S EXPERIMENTS.

Number of trials.	Length in terms of smallest side.	No. of lbs. per square inch causing first flexure.	No. of lbs. per square inch causing fracture.	Number of trials.	Length in terms of smallest side.	No. of lbs. per square inch causing first flexure.	No. of lbs. per square inch causing fracture.
Mean of set of 5 trials	6	3328	4984	Mean of set of 4 trials . .	16	2002	3565
Do. of 4 trials	8	3925	5015·4	Do. of do.	18	1177	3365
2 sets . . .	14	7253	9999·4	2 sets . . .	34	3179	6930
Average . .	7	3626·5	4999·7	Average . . .	17	1589·5	3465
Mean of set of 4 trials	12	2616	4317	Mean of set of 4 trials . .	24	1395	2773
Do. of do.	12	2609	4933	Do. of 5 do.	24	1038	2949
2 sets . . .	24	5225	9250	2 sets . . .	48	2433	5722
Average . .	12	2612·5	4625	Average . . .	24	1216·5	2861
				Average of 4 trials	36	644	1722

* *Note by Editors.*—These numbers should be 11082 and 1231·33 respectively, but as the error may be in the numbers of some of the individual experiments, the text is left as supplied by the author.

	Length in terms of smallest side.	No. of lbs. per square inch causing first flexure.	No. of lbs. per square inch causing fracture.
Mean of 9 trials by Girard . . . . Mean of 8 trials in 2 sets by Lamandè	17·6132 + 17·	1570·55 + 1589·5	3378·55 + 3465·
2 means	34·6132 +	3160·05 +	6843·55 +
Average . . . . Correction—deduct . . .	17·306611+ ·306611 + add	1580·0277+ 58·4303	3421·777 + 92·0916
Corrected average	17·	1638·4581	3513·8694
Mean of 9 trials by Girard . . . . Mean of 9 trials in 2 sets by Lamandè	23·22755 + 24·	1238·222 + 1216·5 +	2777·222 + 2861·
2 means	47·22755 +	2454·722 +	5638·222 +
Average . . . . Correction—add	23·61377 + ·38622 + deduct	1227·3611+ 20·3763	2819·111 + 36·2078
Corrected average	24·	1206·9848	2782·9033

RECAPITULATION.

Number of trials.	Length in terms of smallest side.	No. of lbs. per square inch causing first flexure.	No. of lbs. per square inch causing fracture.
7	7	3626·5	5000
8	12	2612·5	4625
17	17	1638·5	3514
18	24	1207	2783
4	36	644	1722

It is stated in Tredgold's 'Carpentry,' Art. 130, that according to the experiments of Rondelet, "when the height of a square post is less than seven or eight times the side of its base, it cannot be bent by any pressure less than that which would crush it." Lamandè's experiments, though leading to a different conclusion as to small flexures, confirm this remark as to ultimate deflection and fracture, and we derive from them 5000 lbs. as the crushing force for a cubic inch of French oak, which make $= F \times 1$. Each of the other weights will thus be F multiplied by twice the number of lbs. given by the experiments, with the decimal point placed before it, and having been determined for the five lengths, 7, 12, 17, 24, and 36, the multiples for intermediate lengths are filled in by proportion.

Table of Weights causing Flexure and Fracture of Beams by direct Compression.

Length in terms of smallest side.	Pressure per square inch causing first flexure in terms of F (the crushing force).	Pressure per square inch causing fracture in terms of F (the crushing force).	Length in terms of smallest side.	Pressure per square inch causing first flexure in terms of F (the crushing force).	Pressure per square inch causing fracture in terms of F (the crushing force).
1	·9792	1	22	·2628	·5941
2	·9361	1	23	·2520	·5753
3	·8933	1	24	·2414	·5566
4	·8508	1	25	·2310	·5381
5	·8086	1	26	·2208	·5198
6	·7668	1	27	·2108	·5016
7	·7253	1	28	·2009	·4835
8	·6841	·9968	29	·1912	·4656
9	·6432	·9877	30	·1817	·4478
10	·6026	·9727	31	·1724	·4302
11	·5624	·9518	32	·1633	·4127
12	·5225	·9250	33	·1544	·3954
13	·4829	·8923	34	·1457	·3783
14	·4436	·8537	35	·1372	·3613
15	·4046	·8093	36	·1288	·3444
16	·3660	·7590	37	·1206	·3277
17	·3277	·7028	38	·1126	·3111
18	·3079	·6708	39	·1048	·2947
19	·2964	·6514	40	·0972	·2784
20	·2850	·6322	41	·0898	·2623
21	·2738	·6131	42	·0826	·2463[81]

To apply the Table, divide the length of the post by the smallest side and look out the quotient in the first column; take the corresponding decimals from the second and third columns, and multiply each of them by F (the crushing force per square inch) and by the area of the cross section in square inches, and the products will be the weights causing respectively first deflection, or fracture.

The actual dimensions of the lower division, *a h*, of the principal rafter in figure 20, are $72''{\cdot}75 \times 5'' \times 6''{\cdot}90625$ (Art. 54). Its length then in terms of its smallest side is $\frac{72''{\cdot}75}{5''} = 14{\cdot}55$, the decimals corresponding with which in the Table are ·42215 and ·82928, and its cross section is $5'' \times 6''{\cdot}90625$.

[81] It is remarked (Tredgold's 'Carpentry,' Art. 124), that "The weight which broke the specimen is always about twice that which produced the deflection both in Girard's and Lamandè's experiments." The Table shows this to be the case when the length is 15 times the side, but not otherwise. With a length of 42 times the side, the proportions are 3 to 1, nearly, and 3 to 2 when the length is rather more than 8 times the side.

But the latter dimension as given by Barlow's formula would be $6''\cdot7199$. Substituting this then for the purpose of comparing the results of this Table and of Mr. Barlow's formula, we have the cross section $= 5'' \times 6''\cdot7199 = 33\cdot5995$ square inches. Then $\cdot42215 \times$ (F[82] $=$) 6911 lbs. $\times\ 33\cdot5995 = 98026$ lbs. $= 3\cdot4168$ W, is the pressure to cause the first deflection, and $\cdot82928 \times 6911$ lbs. $\times\ 33\cdot5995 = 192564$ lbs. $= 6\cdot7120$ W, is the pressure to cause fracture.

The length of the middle portion hf of the principal is $76''\cdot21$, the quotient of which when divided by the smaller side, $5''$, is $= 15\cdot242$, and the corresponding decimals from the Table are $\cdot3952588$ and $\cdot7971274$. The breadth assigned by Barlow's formula is $6''\cdot4072$, which $\times\ 5''$ gives the cross section $= 32\cdot036$ square inches. Then $\cdot39526 \times 6911$ lbs. $\times\ 32\cdot036 = 87511$ lbs. $= 3\cdot3054$ W, is the pressure to cause first deflection, and $\cdot79713 \times 6911$ lbs. $\times\ 32\cdot036 = 176485$ lbs. $= 6\cdot6661$ W, is the pressure to cause fracture.

The length of the upper portion $fe = 86''\cdot6$ divided by the smaller side $4''\cdot91184$ (assigned by Barlow's formula) gives the quotient $17\cdot63087$, the corresponding decimals to which are $\cdot31521$ and $\cdot68261$, and the cross section would be $5'' \times 4''\cdot91184 = 24\cdot5592$ square inches. The pressures therefore will be $\cdot31521 \times 6911$ lbs. $\times\ 24\cdot5592 = 53500$ lbs. $= 2\cdot9587$ W, causing first deflection, and $\cdot68261 \times 6911$ lbs. $\times\ 24\cdot5592 = 115859 = 6\cdot4074$ W, causing fracture.

And the means of the pressure found as above by the Table are $3\cdot2283$ W to produce the first deflection, and $6\cdot5952$ W to produce fracture.

56. Besides the direct pressure, there is a transverse pressure on the principal rafter, caused partly by its own weight and partly by the weight of the roof and action of the wind at points intermediate between the fulcra, which it is not possible to avoid entirely; and as of the three divisions of the principal the upper division is chiefly affected by transverse strains, it may be useful to inquire what their effect is, and whether in conjunction with the direct strain it is sufficient to require an increased scantling for this portion of the rafter.

[82] The value of F for Indian teak wood not being ascertained by direct experiment, has been deduced from (f) the value of direct cohesion, by the formula $W \times nt = W' \times nc$ (Barlow's Essay, Art. 120) or $f \times$ area of tension $\times$ distance of its centre of gravity from the neutral axis $= F \times$ area of compression $\times$ distance of its centre of gravity from the neutral axis, which in a beam of teak 1 inch square is 15550 lbs. (Barlow's Essay, Art. 143, Table of data) $\times\ ''\cdot4 \times ''\cdot2 = F \times ''\cdot6 \times \cdot3$, making $F = 6911$ lbs.

To find the transverse strength of a rectangular beam supported at both ends and weighted at the centre, the following formula is given (Barlow's Essay, Tredgold's application, Art. 154, Problem 3), $W = \frac{4 S a d^2}{\left(1 + \frac{4 \Delta^2}{l^2}\right) l}$.[83]

In the present instance, the weight of the principal from e to f being uniformly distributed produces only half the strain of an equal weight at the centre.[84] Also the strains of the pressures of the wind at t, and of the wind and roof at r, will be to the strains of the same pressures at the centre of ef, as $\cdot'375 \times 5'\cdot875 : 3'\cdot125 \times 3'\cdot125$, and the strain of a pressure at v will be as $\cdot'75 \times 5\cdot'875$ to the same, these being the rectangles of the respective distances from the fulcra to the points of pressure.

The weight of the principal from e to f is 58·7 lbs. (Art. 48, note 47), but only that portion of it which produces the medial deflection between e and f = 28·3304 lbs. is effective there, and the stress of this weight at right angles with the principal is 28·3304 lbs. × ·866 (Art. 41) = 24·534 lbs. In the same manner, from the actual pressures of the roof and wind must be excluded those portions which are exhausted in producing the fulcral deflection at f, as having no tendency to strain the beam between e and f. Thus the real weights of roof acting between e and f are at $v = 1411\cdot44$ lbs., and at $r = 629\cdot575$ lbs.,[85] which being multiplied by ·866 give the transverse stresses at those points = 1222·307 lbs. and 545·212 lbs. respectively. Also the transverse force of the wind may be at $t = 893\cdot35$ lbs. and at $r = 408\cdot503$ lbs.[86] And the equivalents of all these forces acting on the centre of ef would be $\frac{24\cdot534 \text{ lbs.}}{2} = 12\cdot267 \text{ lbs.} + 1222\cdot307 \text{ lbs.} \times \frac{\cdot'75 \times 5'\cdot5}{3'\cdot125 \times 3'\cdot125} = 516\cdot3025 \text{ lbs.} + (545\cdot212 \text{ lbs.} + 893\cdot35 \text{ lbs.} + 408\cdot503 \text{ lbs.}) \times \frac{\cdot'375 \times 5'\cdot875}{3'\cdot125 \times 3'\cdot125} = 414\cdot8508$ lbs. Total strain at the centre = 943·42 lbs.

[83] Δ Ultimate deflection of the beam $= \frac{l^2}{dU}$, U being = 818 in teak.

S Transverse strength of a square inch = 2488 lbs. in teak (Barlow's Essay, Art. 143, Table).

[84] Barlow's Essay, Art. 112, and Tredgold's practical application, Art. 154, Prob. 3, note 1; also Hutton's 'Mathematics,' vol. ii. Art. 258, Prop. 50, Cor. 2. The slight deviation from an equal distribution of its own weight, caused by the tapering of the principal, is neglected here.

[85] These are the values of the two medial deflections at v and at r, as found by the third method described in note 44, Art. 47.

[86] Art. 51, notes 57 and 61, $t = \cdot5279\,E - \cdot63764\,x = \cdot508452\,E = 893\cdot3502$ lbs. $r = \cdot2314\,F - \cdot0075\,H = 408\cdot5028$ lbs.

Now the resistance of ef to fracture by a transverse strain at the centre is $\frac{4\,S\,a\,d^2}{l+\frac{4\,\Delta^3}{l'}} = \frac{4 \times 2488 \text{ lbs.} \times 5'' \times 5''{\cdot}21875^2}{86''{\cdot}6 + \frac{4 \times 86''{\cdot}6^3}{5''{\cdot}21875^2 \times 818^2 \text{ lbs.}}} = 15623$ lbs., and the resistance to fracture in the same direction by direct compression of its ends is $\frac{C\,a\,d^2}{d + 6\,c + \frac{6\,l^2}{d\,U}}$ (Art. 54) $= \frac{15550 \text{ lbs.} \times 5'' \times 5''{\cdot}21875^2}{5''{\cdot}21875 + 10''{\cdot}4375 + \frac{6 \times 86''{\cdot}6^2}{5''{\cdot}21875 \times 818}}$ [87] $= 86592$ lbs. The actual strain by direct compression is $= 18082$ lbs. (Art. 52), and the actual transverse strain we have shown to be $= 943{\cdot}42$ lbs., which should be equivalent to a direct compression of $943{\cdot}42 \text{ lbs.} \times \frac{86592 \text{ lbs.}}{15623 \text{ lbs.}} = 5229$ lbs., the resistances of the beam ef to these two sorts of pressure being as the parts of this fraction, or as 15623 to 86592. Add together the actual direct compression $= 18082$ lbs. and the equivalent of the transverse pressure $= 5229$ lbs., and we find that their sum ($= 23311$ lbs.) exceeds by 1663 lbs. the fourth of the resistance, $\left(\frac{86592 \text{ lbs.}}{4} = 21648 \text{ lbs.}\right)$ which it is recommended (Art. 54) not to exceed. A slight addition to the depth of this part of the principal might therefore be thought advisable.

57. Direct and transverse strains of the tie-beam.—The tie-beam, like the principal, in this truss (fig. 20) is not subjected to an equal strain throughout its length. The extreme divisions suffer a greater tension than those adjoining, and the central division the least of the whole.[88]

The tension of the central division K K of the tie-beam will be,

From the weight of the roof $= {\cdot}866\,C$ (Art. 39) $+ 1{\cdot}732\,e + 1{\cdot}0952\,f + {\cdot}5349\,h$ (Art. 47, Recapⁿ.) $+ {\cdot}9169\,I$ (Art. 48, Recapⁿ.) $= {\cdot}866 \times 1585$ lbs. $+ 1{\cdot}732 \times 1473$ lbs. $+ 1{\cdot}0952 \times 2419$ lbs. $+ {\cdot}5349 \times 2657{\cdot}5$ lbs. $+ {\cdot}9169 \times 77{\cdot}5$ lbs. (Art. 52)	=	8065 lbs.
From the weight of the ceiling $= 1{\cdot}732\,K$ (Art. 49) $+ {\cdot}9169\,I$ (Art. 48) $= 1{\cdot}732 \times 1130$ lbs. $+ {\cdot}9169 \times 1201{\cdot}75$ lbs. (Art. 52)	=	3059 ,,
From the possible force of wind $= {\cdot}5294\,C + 2\,e + 1{\cdot}2647\,f + {\cdot}6176\,h$ (Art. 51, Recapⁿ.) $= {\cdot}5294 \times 1300$ lbs. $+ 2 \times 864$ lbs. $+ 1{\cdot}2647 \times 1189$ lbs. $+ {\cdot}6176 \times 997$ lbs. (Art. 52)	=	4535 ,,
Total = the pressure on the upper division of the principal, 18082 lbs. (Art. 52) $\times {\cdot}866$	=	15659 ,,

[87] In this case the effort to break the beam is in direction of the larger side, which therefore becomes d, and the smaller side a (see Art. 54, note 74).

[88] For this reason, when the tie-beam is not of one piece it should be scarped in the centre, except with a king-post. Dovetailed mortises to receive tenons from the queen-posts would for the same reason be unobjectionable in the tie-beam of fig. 20. In tie-beams with fewer divisions they may also be used, provided the section of the mortise cut to receive the queen-post does not exceed the section of the mortise which receives the end of the principal rafter.

The tension of each of the divisions from K to I of the tie-beam will be,

From the weight of the roof $= \cdot 866\,C + 1\cdot 732\,(e+f) + \cdot 8458\,h + 1\cdot 45\,I$	$= 10473\cdot 5$ lbs.
From the weight of the ceiling $= 1\cdot 732\,K + 1\cdot 45\,I$	$= 3699\cdot 5$,,
From the possible force of wind $= \cdot 5294\,C + 3\cdot 1628\,e + 2f + \cdot 9767\,h$.	$= 6772$,,
Total	$= 20945$,,

The tension of each of the extreme divisions from I to a of the tie-beam will be,

From the weight of the roof $= 1\cdot 732 \times \left(\frac{C}{2} + e + f + h + I\right)$	$= 12850\cdot 5$ lbs.
From the weight of the ceiling $= 1\cdot 732 \times (K + I)$	$= 4038\cdot 5$,,
From the possible force of wind $= \cdot 5294\,C + 3\cdot 7779\,e + 2\cdot 3889\,f + 1\cdot 1666\,h$	$= 7956$,,
Total = the pressure on the lower division of the principal, $28689\cdot 5$ lbs. $\times \cdot 866$	$= 24845$,,

In regard to the transverse strains of the tie-beam, there is one constant strain arising from the weight of the ceiling, which acts with the greatest effect on the extreme divisions between I and S (fig. 20), and is equal to a weight of 611 lbs.[89] equally spread over this portion, or 305 lbs. at the centre, a weight so small as to require no further attention.[90]

But the beam may occasionally be subjected to a heavy strain from the force of the wind communicated through one of the iron rods. This strain being resolved into its horizontal and vertical effects, the latter may exert a lift $= 4196$ lbs.[91] However, before this strain can affect the tie-beam, it must overcome the opposite tension of the iron rod from the weight of the roof and ceiling, the value of which transversely to the beam is $= 2820$ lbs.,[92] reducing the strain to $4196 - 2820 = 1376$ lbs., being the greatest possible transverse strain to which any part of the tie-beam can be exposed.

[89] This weight is i' (Art. 49) $= 578$ lbs., to which add a proportional share of the weight of the tie-beam $= 33$ lbs.

[90] In Tredgold's 'Carpentry,' Art. 181, is the following remark, that "in estimating the strength (of the tie-beam) the thrust of the rafters need not be considered, because the beam is always sufficiently strong to resist the strain." On the contrary, in the present instance, and almost always, the thrust of the rafters is the principal strain, and should regulate the strength of the tie-beam.

[91] The lift is $= 2\cdot 1812\,e + 1\cdot 3793\,f + \cdot 6736\,h$ (Art. 51, Recap^n.) $= 4196$ lbs.

[92] The tension of the iron rod by the weight of the roof is $\cdot 6061\,h$ (Art. 49, Recap^n.) $= 1610\cdot 7$ lbs., its value in direction of gravity being $\frac{1610\cdot 7 \text{ lbs.}}{1\cdot 039 \text{ (Art. 48)}} = 1550\cdot 25$ lbs., to which add the weight of the ceiling on I $= 1201\cdot 75$ lbs., and a proportion of the tie-beam $= 68$ lbs. Total $= 2820$ lbs.

58. Resistance of the tie-beam to direct and transverse strains.

The power of direct cohesion in teak of specific gravity 745 is = 15550 ℔s. (Barlow's Essay, Art. 143, Table) per square inch. The transverse area of the beam being 25 square inches (Art. 43), would give it an absolute strength of 25 × 15550 ℔s. = 388750 ℔s.; but assuming that the line of strain does not coincide with the axis, the following formula is given (Barlow's Essay, Tredgold's practical application, Art. 154, Prob. 2) for the resistance to tension, namely, $\frac{C\,a\,d^2}{d + 6\,\delta} = W$, and if we take the deviation of the strain, δ, at one-third of the thickness, we have W = one-third of the absolute strength = 129583 ℔s. = 5·2157 times the tension, which is 24845 ℔s. (Art. 57). This section therefore would be more than sufficient, were it not cut into by the mortise for the principal, to the extent of about 5 square inches or one-fifth of the transverse area, which reduces the resistance to little more than four times the strain, a proportion proper to be kept between the two.

In the preceding Article it was shown that the tie-beam might occasionally be exposed to a transverse strain of 1376 ℔s. at the point N, fig. 21, and the nearest points of effective resistance to this force which acts upwards, must be taken as the extreme points a and n where the beam receives the pressure of the principal rafters, and from which the point of strain is distant respectively 33′ and 9′. Then applying the formula $\frac{S\,l\,a\,d^2}{m\,n} = W$ (Barlow's Essay) we have the resistance to fracture $= \frac{2488 \text{ ℔s.} \times 504'' \times 5'' \times 5''^2}{396'' \times 108''} = 3665$ ℔s. = 2·6635 times the strain. The tension of the beam also increases its transverse strength considerably.[93]

[93] The resistance of a direct force E extending a beam, to any certain deflection δ caused by a transverse force W, is $\frac{l\,\delta\,E}{m\,n}$, which becomes $\frac{4\,\delta\,E}{l}$ when W acts at the centre. For, in the following figure let N C be the deflection of a cord suspended from the extremities of a beam $a\,n$, and let it also represent the force causing that deflection. A N, A N will then express the two opposite and equal compressions (Art. 3) of the beam at a and n, and it may be shown by similar triangles that A N is $= \frac{a\text{N} \times \text{N}n}{a\text{N} + \text{N}n}$. The force then required to counteract the compression at a or n is to the transverse force causing it as A N to N C, or E : W :: $\frac{m\,n}{l}$: δ, making $W = \frac{l\,E\,\delta}{m\,n}$. Now allowing the deflection to be one inch in the present instance, we have

Fig. N.

59. The direct compression of the straining beam $e\,e$, fig. 20, will be,

From the weight of the roof, the same as the tension of the central division of the tie-beam (Art. 47, Recap^n.), diminished however by the thrust of the small upper principal, namely, $\frac{1 \cdot 5398}{2} \times$ C, $= 8065$ ℔s. $- \cdot 7699 \times 1585$ ℔s. (Art. 57)	$= 6845$ ℔s.
From the weight of the ceiling, same as tension of central division of tie-beam	$= 3059$,,
From the possible force of wind, same as tension of central division of the tie-beam, diminished by $(\cdot 5294 - \cdot 05875) \times$ C (Art. 51, Recap^n.) $= 4535$ ℔s. $- \cdot 47065 \times 1300$ ℔s.	$= 3923$,,
Total	$= 13827$,, [94]

60. The dimensions of the straining beam are $96'' \times 5'' \times 4\frac{1}{2}''$, taking its extreme length from the intersections of axes, e, e, and its resistance to direct compression will be $\dfrac{\mathrm{C}\,a\,d^2}{d + 6\,c + \dfrac{6\,l^2}{d\,\mathrm{U}}}$ (Art. 54) $= 55201$ ℔s. $= 3 \cdot 9923$ times the strain W.[95]

61. The stress on each of the small upper principals $c\,e$, fig. 20, is $\frac{1 \cdot 836}{2} \times$ C (Art. 39, note) $= \cdot 918 \times [1585$ ℔s. $+ 12$ ℔s.] (Art. 48, note 46) $= 1466$ ℔s. from the weight of the roof, to which add the possible pressure from wind $= \cdot 5612$ C (Art. 51, Recap^n.) $= \cdot 5612 \times 1300$ ℔s. $= 730$ ℔s., giving a total direct pressure of 2196 ℔s. This principal is a piece of a common rafter, 3 inches in diameter, and 5 feet in length, 6 inches of which project beyond c, and its resistance to direct pressure, taking $\frac{3}{5}$ths of that given by the formula $\dfrac{\mathrm{C}\,a\,d^2}{d + 6\,c + \dfrac{6\,l^2}{d\,\mathrm{U}}}$ (Barlow's Essay, Tredgold's application, Art. 163, Prob. 7), is $= 15618$ ℔s. $= 7 \cdot 112$ W.

62. The direct compression of either of the upper struts f K, fig. 20,

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$\frac{l\,\mathrm{E}\,\delta}{m\,n}$ or $\frac{504'' \times 24845 \text{ ℔s.} \times 1''}{396'' \times 108''} = 293$ ℔s. for the resistance to this deflection arising exclusively from the tension of the tie-beam, and the resistance from the same cause to transverse fracture would be $\left(\text{taking the ultimate deflection} = \frac{4\,m\,n}{d\,\mathrm{U}}\right)$ no less than 12246 ℔s.

[94] The compression of the straining and the tension of the tie-beam (central portion) become equal by omitting the upper principals.

[95] If we apply the Table, Art. 55. Length $96'' \div$ smaller side $4'' \cdot 5$ is $= 21\frac{1}{3}$, the corresponding decimals to which are $\cdot 27013$ and $\cdot 60676$, and the cross section is $5'' \times 4'' \cdot 5 = 22 \cdot 5$, giving $\cdot 27013 \times 6911$ ℔s. $\times 22 \cdot 5 = 42005$ ℔s. $= 3 \cdot 0379$ W for the pressure causing first deflection, and $\cdot 60676 \times 6911$ ℔s. $\times 22 \cdot 5 = 94350$ ℔s. $= 6 \cdot 8236$ W for the pressure causing fracture.

From the weight of the roof is $\cdot 8974 f + \cdot 4382\, h + \cdot 7513\, \mathrm{I}$ (Arts. 47, 48, Recapⁿ.)	= 3393·5 lbs.
From the weight of the ceiling, $\cdot 7513\, \mathrm{I}$	= 903 ,,
From the possible force of wind, $1{\cdot}03625 f + \cdot 5061\, h$ (Art. 51, Recapⁿ.)	= 1736·5 ,,
Total	= 6033 ,,

The dimensions of the strut[96] are $8'{\cdot}25 \times 3''{\cdot}5 \times 4''$ (Art. 43), and its strength to resist direct compression by formula $\dfrac{\mathrm{C}\, a\, d^2}{d + 6\, c + \frac{6\, l^2}{d\, \mathrm{U}}}$ is 24547 lbs. = 4·0688 times the pressure W.[97]

63. The direct compression of each of the lower struts, h I, fig. 20,

From the weight of the roof is $\cdot 92795\, h$ (Art. 47, Recapⁿ.)	= 2466 lbs.
From the possible force of wind, $1{\cdot}0715\, h$ (Art. 51, Recapⁿ.)	= 1068 ,,
Total	= 3534 ,,

The dimensions of the lower strut being $4'{\cdot}2 \times 2''{\cdot}25 \times 2''{\cdot}75$ (Art 43), its resistance to direct compression by formula $\dfrac{\mathrm{C}\, a\, d^2}{d + 6\, c + \frac{6\, l^2}{d \times \mathrm{U}}}$ will be = 14403 lbs. = 4·07555 W.[98]

64. The queen-post is exposed to a direct tension from the weight of the roof $= \cdot 6323 f + \cdot 3088\, h + \cdot 5294\, \mathrm{I}$ (Arts. 47, 48, Recapⁿˢ.) besides a portion of weight depending

From e (Art. 48), namely, queen-post and parts of tie-beam and strut, 129 lbs.	= 2519 lbs.
From the weight of the ceiling, $\mathrm{K} + \cdot 5294\, \mathrm{I}$	= 1766 ,,
From the possible force of wind, $\cdot 73015 f + \cdot 3566\, h$ (Art. 51, Recapⁿ.)	= 1224 ,,
Total	= 5509 ,,

The transverse section of the queen-post being $5'' \times 2''{\cdot}4$ (Art. 43), its resistance to tension, taking it at one-third of the absolute strength (Art. 58), will be 62200 lbs. = 11·2906 W.[99]

The cross section of the iron tie-plate is $1'' \times \frac{1}{4}''$, the absolute strength of

[96] The dimensions of the struts and queen-post are exclusive of their tenons.

[97] The Table, Art. 55, gives the deflecting pressure for this strut = 19167 lbs. = 3·177 W, and the breaking pressure = 46287 lbs. = 7·6723 W.

[98] By the Table, Art. 55, the deflecting pressure for this strut is 11054 lbs. = 3·1251 W, and the breaking pressure = 25084 lbs. = 7·0979 W.

[99] The perforation, for the tie-bolt of $\frac{5}{8}$ of an inch in diameter, through the depth of the queen-post, will reduce its strength by more than one-fourth, leaving it however still greater than 8 W.

which is about 15000 lbs.,[100] and the strength by formula $\frac{C a d^2}{d + 6\delta}$ would be 5000 lbs., which has to support half the strain, the plate being doubled, and is only $= 1{\cdot}8152$ W.[101]

65. The strain on each of the iron rods, I f, fig. 20,

From the weight of the roof is $\cdot6061\ h + 1{\cdot}039$ I (Arts. 47, 48, Recapns.) + part of itself depending from f, 5·407 lbs. (Art. 48)	= 1696·5 lbs.
From the weight of the ceiling = 1·039 I	= 1248·5 ,,
From the possible force of wind, ·6999 h (Art. 51, Recapn.) . . .	= 698 ,,
Total	= 3643 ,,

The transverse section of the iron rod is $= \frac{3}{4}'' \times \frac{3}{4}'' \times \cdot7854 = \cdot4418$ square inches (Art. 43), having an absolute strength of $\cdot4418 \times 60000$ lbs. = 26508 lbs., or by the formula, when the strain is not in the centre, $= \frac{26508 \text{ lbs.}}{3} = 8836$ lbs. $= 2{\cdot}4255$ W.[101]

66. The stresses on the three purlins are not exactly the same, but as they nearly correspond with one another, it will suffice to consider the strain on the lower purlin, which is somewhat the heaviest of the three.[102]

The weight of roof on the lower purlin H, fig. 20, is 2146 lbs. (Art. 45), and produces strains in directions of its depth and width respectively equal to 2146 lbs. $\times \cdot866 = 1858$ lbs. and to $\frac{2146 \text{ lbs.}}{2} = 1073$ lbs. (Art. 41). In addition to this, the possible strain from wind, in direction of its depth, is ·58065 H (Art. 51), $= \cdot58065 \times 1902$ lbs. (Art. 50) $= 1104$ lbs., making that strain = 1858 lbs. + 1104 lbs. = 2962 lbs.

Now the dimensions of the purlin are $10' \times 4\frac{1}{4}'' \times 6\frac{3}{4}''$ (Art. 43), and its absolute power of resistance to transverse fracture in direction of its depth, by formula $\frac{4 S a d^2}{l} \times 2 = W$,[103] is $\frac{4 \times 2480 \text{ lbs.} \times 4''{\cdot}25 \times 6''{\cdot}75^2}{120''} \times 2 = 32015$ lbs.

[100] 60,000 lbs. per square inch.

[101] 2 W, which makes the absolute strength = 6 times the strain, is sufficient in wrought iron, in regard of its superior strength, tenacity, and flexibility, as compared with timber.

[102] The weights of roof on the purlins E and F, fig. 20, are respectively 2163 lbs. and 1966 lbs. (Art. 45), and the possible strains on them in direction of this depth, from the wind, are ·5279 E (Art. 51) = ·5279 × 1757 lbs. (Art. 50) = 927·5 lbs., and ·5414 F = ·5414 × 1827 lbs. = 989 lbs.

[103] This formula, given in Barlow's Essay, Tredgold's practical application, Art. 154, Prob. 4, in which the simple length is the divisor, is sufficiently accurate, and in this case makes S = 2480 lbs. instead of 2488 lbs. (see Art. 56, note 83). The strength is multiplied by 2 in this instance, because the stress is equally spread over the whole length of the purlin.

$= 10{\cdot}8$ W. But the strength should in all cases be such as to allow of a certain deflection only, which Tredgold recommends should not exceed one inch in 40 feet, or $\frac{l}{480}$, and to find the deflection we have the following formula, namely, $\delta = \frac{\frac{5}{8}\,\mathrm{W} \times l^3}{\mathrm{E} \times a \times d^3}$,[104] which, applied in the present instance, makes it $= \frac{\frac{5}{8} \times 2962 \text{ lbs.} \times 120''^3}{9{,}657{,}802 \text{ lbs.} \times 4''{\cdot}25 \times 6''{\cdot}75^3} = {\cdot}''2534 = \frac{l}{473\frac{1}{2}}$.

Also for the deflection of the purlin H in direction of its width, we have $\frac{\frac{5}{8} \times 1073 \text{ lbs.} \times 120''^3}{9{,}657{,}802 \text{ lbs.} \times 6''{\cdot}75 \times 4''{\cdot}25^3} = {\cdot}''2316 = \frac{l}{518}$.

67. The ridge-pole sustains a weight of roof = 1585 lbs. (Art. 45), to which may be added a vertical pressure from the possible force of wind = ·6113 C (Art. 51) = ·6113 × 1300 lbs. (Art. 50) = 795 lbs., making a total of 2380 lbs.[105]

The dimensions of the ridge-pole being $10' \times 2''{\cdot}5 \times 7''{\cdot}5$ (Art. 43), give the deflection $= \frac{\frac{5}{8} \times 2380 \text{ lbs.} \times 120''^3}{9{,}657{,}802 \text{ lbs.} \times 2''{\cdot}5 \times 7''{\cdot}5^3} = {\cdot}''25235 = \frac{l}{475\frac{1}{2}}$.

68. The transverse pressure on one division of a common rafter from purlin to purlin, is,

From the weight of the roof $= 6'{\cdot}35 \times 1'{\cdot}25 \times 30{\cdot}5175 \text{ lbs.} \times {\cdot}866$ (Arts. 41, 42, 43)	= 210 lbs.
And there may be a pressure from the wind $= 6'{\cdot}35 \times 1'{\cdot}25 \times \frac{57{\cdot}75 \text{ lbs.}}{2}$ (Arts. 40 and 50)	= 229 ,,
Total	= 439 ,,

And the deflection will be $\frac{\frac{5}{8} \times 439 \text{ lbs.} \times 6'{\cdot}35^3}{5589 \text{ lbs.} \times 3'' \times 3''^3}$ ×[106] $1{\cdot}7 = {\cdot}''2638 = \frac{l}{289}$.[107]

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104 Barlow's Essay, Tredgold's practical application, Art. 154, Prob. 6. The value of E for teak is to be found in the Table, Art. 143, and by taking l, in the formula, in feet, it becomes $\frac{9{,}657{,}802 \text{ lbs.}}{1728} = 5589$ lbs.

105 When the small upper principals are omitted, which is commonly done, the ridge-pole, instead of supporting the rafters, rests on them, and need then be nothing more than a bond to which they must be securely fastened by clenching the nails (see notes to Arts. 46 and 47). The weight on the upper purlins is in this case much increased, and that on the central purlins diminished.

106 Barlow's Essay, Tredgold's practical application, Art. 153, Prob. 6.

107 This deflection being so much greater than $\frac{l}{480}$, shows that the common rafters in this roof, if they were in short pieces, would be too far apart; but as they are supposed to be in one length from ridge to eave (Art. 42), they are in their central divisions liable to about half only of the deflection above found, and the deflections of the outer divisions are also greatly diminished (Art. 36, note).

69. The pressure on a batten is,

From the weight of the roof. $= 1' {\cdot} 25 \times 0' {\cdot} 333^{+} \times (30{\cdot}5175$ lbs. $- 1{\cdot}8285 - 0{\cdot}024$ lbs.) $\times {\cdot}866$ (Arts. 41, 42, 43) . . .	$= 10{\cdot}3433$ lbs.
And may be from the wind $= 1'{\cdot}25 \times 0'{\cdot}333^{+} \times \frac{57{\cdot}75 \text{ lbs.}}{2}$ (Arts. 40, 50) .	$= 12{\cdot}0312$,,
Total	$= 22{\cdot}3745$,,

And the deflection would be $\frac{\frac{5}{8} \times 22{\cdot}3745 \text{ lbs.} \times 1'{\cdot}25^3}{5589 \text{ lbs.} \times 2'' \times (\frac{3}{8}'')^3} = {\cdot}''046335 = \frac{l}{324}$; but as the battens generally cover several intervals, and are also nailed, the deflection will be little more than half of the above (note, Art. 36).

70. The more important of the conclusions at which we have arrived in the foregoing Articles may be thus summed up ;—

1st. That in compound trusses the strains on the lower divisions of the principal rafters and the extremities of the tie-beam, are the same as they would be in a simple trilateral truss having the whole weight (exclusive of that resting directly on the walls) at its apex (Arts. 8, 46, 47).

2nd. That the most advantageous transverse section for rectangular beams subjected to direct pressure, such as the principal rafters, straining beam, and struts, is when the sides are proportioned as 11 to 12 (Art. 53). If subjected also to transverse strains, proportionate additions must be made to the depths of the section (Art. 56).

3rd. That the strength of the tie-beam should be regulated by its direct and not by its transverse strain (Art. 57) ; and therefore that the best rectangular section for it is a square.

4th. That the queen-posts, having necessarily the same width as the principal rafters, may be reduced in their depth to the smallest dimension of which the straightness of grain in their material will admit (Art. 64, and note). If, however, the queen-post be dovetailed into the tie-beam, and the iron strap dispensed with, regard must be had to the strength of the tenon (note to Art. 57).

5th. That, in a roof sloping at 30° from the horizon, and taking into account the possible pressure from wind, the proper proportions for the width and depth of a purlin are about as 17 to 27 (Art. 66). Much strength is gained by carrying a purlin over two or more intervals, or even by prolonging its ends (note to Art. 36).

6th. With respect to the application of iron ties to connect the tie-beam and principals, they are unnecessary in teak timber, but the tenon of the principal should penetrate to the centre of the tie-beam, and its ends should be cut off at right angles to the axis of the principal (Art. 52).

7th. The truss is subject on the leeward side to heavy strains from wind (Art. 51, Recap^{n}.).[108] These might either be counteracted by bands connecting the principals with the straining and tie-beams, in which case the strains are reduced to those of a simple trilateral truss (Arts. 22 to 25), or they might be much reduced by diagonal ties between the queen-posts; but, except in very large roofs, such precautions may be dispensed with.

8th. A camber of not less than 1 inch for each length of 12 feet should be given to the tie-beam. After the truss shall have been some time loaded with the roof and ceiling, the tie-beam will be found nearly straight.[109]

9th. It is recommended that the rafter nails at the ridge-pole be secured by clenching. The purlin blocks may then be dispensed with, as also the upper principals, but not in large roofs (notes to Arts. 46, 47).[110]

10th. The following are problems still undetermined, but quite susceptible of an easy solution by experiment; namely, to find, 1st, The pressures on the several fulcra of a beam uniformly loaded and supported at three or more points (Art. 38, and notes); and 2nd, The stiffest proportions for a rectangular post (Art. 53).

71. Rules for finding the scantlings of teak timber for trusses supporting a double-tiled roof, such as described in Arts. 42, 43, with or without a ceiling, as described in Art. 44.

For the tie-beam: From the extreme horizontal span of the roof in feet deduct twice the sum of the horizontal projections in feet of the two eaves beyond the centres of the wall-plates. Multiply the remainder by the distance in feet from truss to truss, and the area thus found by (37 ℔s. + 23 ℔s. =) 60 ℔s. The product will be the direct strain of the tie-beam arising from the weight of the roof and the possible force of wind.

108 Additional strength has been given to the timbers of the truss represented in figs. 20 and 21, for the purpose of resisting these strains. (See Art. 52, note 64, and Art. 57.)

109 The horizontal contraction in the upper or compressed parts of the truss in conjunction with the extension of the tie-beam may be taken at 1 inch in 12 feet, which would cause a vertical depression in the tie-beam of $3\frac{1}{3}$ inches at the queen-posts, in a truss of 40 feet span, like that represented in figs. 20, 21. This amount of compression and extension has been actually observed by the writer in one instance, at Ahmednuggur.

110 The writer has seen the purlins and pole-plates partly turned over, and the ridge nails partly drawn, in the roof of a shed at Colaba, near Bombay.

If there be a ceiling: Measure the distance in feet from each wall to the nearest point at which the tie-beam is supported, and deduct half the sum of these two distances from the clear span in feet between the walls. Multiply the remainder by the distance in feet from truss to truss for the area, which, multiplied by $12\frac{1}{2}$ lbs., will give the direct strain caused by the weight of the ceiling.

Divide the whole strain by 1000 lbs., and the quotient will be the square of the side in inches.

Example from the roof represented in figures 20, 21: The extreme span is 50 feet, from which deduct twice the width of the two eaves, or $7'\cdot5 \times 2$, leaving $35'$, which $\times\ 10'$, the distance between the trusses, and by 60 lbs., gives 21,000 lbs. for the strain of the roof and wind. The ceiling has a span of 40 feet, from which deduct half the sum of its two outer divisions $= 8'$, and the remainder, $32' \times 10' \times 12\frac{1}{2}$ lbs., gives a strain $= 4000$ lbs. Total strain $= 25{,}000$ lbs. The square of the side then is $\frac{25000 \text{ lbs.}}{1000 \text{ lbs.}} = 25$, and the side is $5''$.

And for the strain of the roof and wind on the central or any other isolated division of the tie-beam, it will bear nearly the same proportion to the strain on the extremities as the greatest distance of either of its supports from the farther wall does to the whole clear span. In fig. 20, for instance, the strain on K K, the central division, will be to the strain on the extremities as K K S $= 24' : \text{S S} = 40'$, or it is $= 21{,}000$ lbs. $\times \frac{24}{40} = 12{,}600$ lbs.

And to find the strain caused by the ceiling on the central division of the tie-beam, multiply the greatest distance in feet of either of its supports from the farther wall by the distance in feet from truss to truss, and the area thus found by $12\frac{1}{2}$ lbs. for the strain; and for any intermediate division take the mean of a strain found as above, and of a proportion between the strains of the central and extreme divisions. Thus the strain on K K in figure 20 from the weight of the ceiling will be $=$ (K K S $=$) $24' \times 10' \times 12\frac{1}{2}$ lbs. $= 3000$ lbs., and the strain on I I will be a mean between $32' \times 10' \times 12\frac{1}{2}$ lbs. and $\frac{4000 \text{ lbs.} + 3000 \text{ lbs.}}{2}$, or $= 3750$ lbs.

For the principal rafter: The strain is that of the tie-beam $\times\ 1\cdot1547$ (Art. 39). Make the smaller side the same as that of the tie-beam, and divide the length by it.[111] Find the decimals corresponding to the quotient in the

[111] The length only between the two lower fulcra, if there be struts.

second and third columns of the Table in Art. 55, which multiply by 2000 lbs. and by 1000 lbs. respectively, and the strain divided by half the sum of the products will be the rectangle of the two sides in inches.

Example from the roof in figs. 20, 21: The strain is $= 25{,}000$ lbs. $\times$ 1·1547 $= 28{,}867{\cdot}5$ lbs. The length divided by the smaller side is $\frac{72''{\cdot}75}{5''}$ (Art. 54) $= 14{\cdot}55$. The corresponding decimals ·42215 and ·82928, $\times$ 2000 lbs. and 1000 lbs. respectively, and their sum divided by 2, give 837 lbs. as divisor, and $\frac{28{,}867{\cdot}5 \text{ lbs.}}{837 \text{ lbs.}} = 34{\cdot}5$ is the rectangle of the sides; whence we find the depth $= \frac{34{\cdot}5}{5} = 6''{\cdot}9$.

Or it may be found by Mr. Barlow's formula, for which see Art. 54.

The above found is the scantling of the whole principal when there are no struts, otherwise of the lower division only. In the latter case, apply this scantling to the centre of the lower division, and, retaining the width, diminish the depth upwards by $\frac{1}{8}$th inch for each foot of length.

In the truss, figs. 20, 21, the length from the centre of the lower to the centre of the higher division is $13'{\cdot}28$, which requires a diminution of $\frac{13''{\cdot}28}{8}$ $= 1''{\cdot}68$, reducing the depth of the latter to $5''{\cdot}22$.

For the straining beam: The strain is that of the tie-beam where there are no struts, and no small principals abutting on the straining beam; and giving it the same width as the principal, the depth may be found by the same method as for the latter. When there are struts and no upper principals, the strain is that of the central division of the tie-beam; but when there are upper principals, the strain from the roof and wind will be diminished by about $\frac{7}{10}$ths of itself, multiplied by the length of the straining beam and divided by the span; while the strain from the ceiling will remain unchanged.

Example from the roof, fig. 20, of the last supposed case: The strain on the central division of the tie-beam from the roof and wind is 12,600 lbs., from which deduct 12,600 lbs. $\times \frac{7}{10} \times \frac{8'}{40'} = 1764$ lbs. The remainder, $= 10{,}836$ lbs. with 3000 lbs. added to it for the strain from the ceiling, total $= 13{,}836$ lbs., will be the pressure on the straining beam. Now the length divided by the width is $\frac{96''}{5''} = 19{\cdot}2$, and the corresponding decimals from the Table are ·29412 and ·64756, which, multiplied respectively by 2000 lbs. and 1000 lbs. and the sum of the products divided by 2, give 617·9 lbs. for a divisor. Then

$\frac{13{,}836 \text{ lbs.}}{618 \text{ lbs.}}$ makes the section = 22·39 square inches, which, divided by 5″, gives 4″·478 for the depth of the straining beam.

For the queen-post: Make the depth equal to half of the width, the width being that of the tie-beam.

For the struts: If there be only one strut on each side, the strain on it may be taken as equal to one-fourth of the direct pressure on the principal where there is a king-post, and as one-sixth where there are queen-posts. If there be two struts on each side, make the strain on the upper strut = $\frac{3}{14}$ths of the direct strain on the lower division of the principal; and if there be three struts on each side, = $\frac{5}{28}$ths of the same.

For the other struts, make the strain of each = $\frac{7}{10}$ths of the strain on the strut immediately above it for the roof and wind, and also for the ceiling if it have another strut below it; but if itself be the lowest strut, count no strain for the ceiling.

The scantlings may then be found in the same manner as for the principals, the proportions of 11 and 12 being observed as nearly as may be for the width and depth, but trials must first be made to obtain an approximation to the smaller side.

Example from figs. 20, 21: There being two struts on either side, the strain on the upper strut will be $\frac{3}{14}$ths of 28,867·5 lbs. = 6186 lbs. The length of the strut is 99″, and assuming 3″·5 as the smaller side, we have $\frac{99}{3{\cdot}5} = 28\frac{2}{7}$, the corresponding decimals to which are ·1981 and ·4784. Multiply these by 2000 lbs. and 1000 lbs. respectively, and divide the sum of the products by 2, and the strain = 6186 lbs. divided by the quotient = 437 lbs., makes the section = 14·156 square inches, and the larger side will be $\frac{14{\cdot}156}{3{\cdot}5} = 4''{\cdot}045$.

For the iron rod: The strain from the roof and wind may be taken at $\frac{2}{3}$rds of the pressure on the strut which it supports, to which add half the weight of the two adjoining divisions of the ceiling. Divide the strain by from 8000 lbs. to 10,000 lbs., according to the quality of the iron. The quotient is the area of the cross section in square inches.

For the purlin: Multiply the distance from truss to truss by half the sum of the two intervals between the purlin and its neighbouring purlin or plate, measured on the slope, all in feet, and the product multiplied by 46 lbs. will be the strain in direction of its depth, the possible force of wind included.

Then, to find the scantling, employ the formula $\frac{\frac{5}{8}\,\text{W lbs.}\ l''^3}{1728 \times 5589\ \text{lbs.} \times \frac{l''}{480}} = a''\,d''^3$ (Art. 66), or $\frac{\text{W lbs.} \times l'^2}{223{\cdot}56\ \text{lbs.}} = a''\,d''^3$, or $\frac{4}{9}$ lbs. W lbs. l'^2, nearly $= a''\,d''^3$, and take out the width and depth in the proportions of 17 to 27.

Example from the roof in figs. 20, 21: The strain W is $= 10 \times 6{\cdot}35$ (Art. 42) $\times$ 46 lbs. $=$ 2921 lbs., and $\frac{2921\ \text{lbs.} \times 10^2}{223{\cdot}56\ \text{lbs.}}$ or $1306{\cdot}6 = a''\,d''^3$; and $6{\cdot}75^3 \times 4{\cdot}25$ being $= 1307$, therefore $4\frac{1}{4}''$ and $6\frac{3}{4}''$, which are in the required proportions to each other of 17 to 27, are the proper width and depth for the purlin.

But when the small principals above the straining beam are omitted, a portion of the strain on the ridge-pole will generally be transferred to the upper purlins, while the weight on the next purlins will be diminished (Art. 46, note). If there be no purlin blocks, nearly the whole strain of the ridge-pole will come on the upper purlins, and must be divided between them, with the addition of its counterpoise, which will be about as much again (Art. 45). The weight on the second purlins will be reduced by more than half, while the weight on the third purlins will be somewhat increased. As a general rule, therefore, in this case, increase the strain on the upper purlin by the whole strain of the ridge-pole (as it would act in direction of its depth), and halve the strain on the second purlin. In figs. 20, 21, for instance, the strain of the ridge-pole in a vertical direction is 2380 lbs. (Art. 67), and this, multiplied by ·866 for the strain in direction of the depth of the purlin, becomes 2061 lbs., which, added to 2921 lbs., the strain before found for a purlin, makes the total strain on the upper purlin $=$ 4982 lbs., and the strain on the second purlin is reduced to $\frac{2921\ \text{lbs.}}{2} = 1460$ lbs.

For the ridge-pole: Multiply the distance from truss to truss by half the sum of the two distances from the ridge-pole to each of its adjoining purlins, measured on the slope, both in feet, and the product by 38 lbs.; which, with the addition of the weight of the chunam ridge, will be the whole vertical strain, including the effect of wind. Then, to find the scantling, proceed as for the purlins. But if there be no upper principals, make the scantling just sufficient to receive the rafter nails (Art. 46, note 37).

Example from the roof in figs. 20, 21: The strain W is equal to $10 \times 5{\cdot}486$ (Art. 45) $\times$ 38 lbs. $=$ 2085 lbs. plus the weight of the chunam ridge $=$ 280 lbs.

(Art. 43); total 2365 lbs. Then $\frac{2365 \text{ lbs.} \times 10^2}{223{\cdot}56 \text{ lbs.}} = 1058$ is $= a\,d^3$. Make $a = 2''{\cdot}5$, which is a convenient width for receiving the rafter nails, and $\frac{1058}{2{\cdot}5} = 423$, will be the cube of the depth, which will be $7\frac{1}{2}$ inches, the cube of that number being $421\frac{7}{8}$.

For a pole-plate, when the truss is supported by posts: Find the weight of the eave from the centre of the pole-plate downwards, and double it, adding to the product one-third of the difference between the respective weights of the eave and of the division of the roof next above it. The sum will be the vertical strain from the roof and wind. Then proceed to find the scantling as before, making the width the same as that of the posts.

Example from the roof in figs. 20, 21, supposing posts 5 inches square to be substituted for the walls.

The weight of the eave from b to A is $= 97$ lbs. $+ 484$ lbs. $+ 441$ lbs. (Art. 45) $= 1022$ lbs., which $\times 2$ is $= 2044$ lbs. The weight of the roof from A to H is $= 1938$ lbs., and $\frac{1938 \text{ lbs.} - 1022 \text{ lbs.}}{3} = 305$ lbs., which, added to 2044 lbs., makes a total strain of 2349 lbs. Then $\frac{2349 \text{ lbs.} \times 10^2}{223{\cdot}56 \text{ lbs.} \times 5} = 210$ is the cube of the depth, and the depth will be 6 inches, nearly.

72. Comparative view of the scantlings of timber for a trussed roof having a clear span of 40 feet, as given in Tredgold's 'Carpentry' and in this treatise (figs. 20, 21).[112]

	Tie-beam.	Queen-post.	Principal.	Strut.	Purlin.	Common rafter.	Straining beam.
Tredgold . .	$6'' \times 11''$	$6'' \times 4''$	$6'' \times 6''$	$2\frac{1}{2}'' \times 4\frac{1}{2}''$	$5'' \times 8\frac{3}{4}''$	$2'' \times 4\frac{1}{4}''$	$6'' \times 8''$
Figures 20, 21	$5'' \times 5''$	$5'' \times 2\frac{2}{5}''$	$5'' \times 6''$	$\left\{ \begin{matrix} 3\frac{1}{2}'' \times 4'' \\ 2\frac{1}{4}'' \times 2\frac{3}{4}'' \end{matrix} \right\}$	$4\frac{1}{4}'' \times 6\frac{3}{4}''$	3″ diam^r.	$5'' \times 4\frac{1}{2}''$

[112] Trusses nearly resembling that represented in figs. 20, 21 of this treatise, were used in the construction of the camp equipage store-room at Bombay, in 1839, and are found perfectly efficient, though the weight far exceeds that of Tredgold's roof, and a saving of one-third of the timber is effected.

Note.—The Corps of Royal Engineers should be reminded, the Master-General and Board of Ordnance, by their order of the 2nd December, 1844, $\frac{\text{E}}{1599}$, directed that Tredgold's Treatise on Carpentry, as revised by Barlow, should be adopted.—*Editors.*

VI.—*Description of the Mat Covering Sheds used at Hong-Kong in the erection of the Ordnance Buildings, and of the mode adopted by the Chinese in transporting and raising heavy Weights for these Buildings. By Major* Aldrich, *R. E.*

Victoria, Hong-Kong, 21st July, 1846.

For the due erection of buildings of any size at this station, it is necessary to provide a mat covering over the whole area to be built upon, and a little exceeding its dimensions, in order to protect the work from the very heavy rains which fall for six months in summer, and also to protect the workmen from the weather, and from the powerful influence of the sun.

The frame-work and supports for this covering are made of bamboo, of various heights and thicknesses, fastened together with rattan lashings, in no particular order with reference to scantlings, but numerously introduced, and united together with lashings, to obtain sufficient strength to be available for the scaffolding of the proposed building.

To raise the materials for the first and second floors, when they are heavy, separate inclined planes are attached to the sides of the covering at the necessary heights, and are formed of bamboo frame-work, floored with light China fir boards, also lashed together.

Not a nail is used in such a bamboo shed; and when the shed is completed, it has an elegant appearance, representing the creditable ingenuity and ant-like labour of the Chinese for their application of manual power in its simple state. They are very ignorant of the value of machinery, and are very averse to its use.

At this station, all land transport for the Ordnance buildings, for every description of article, has been performed solely by manual labour.

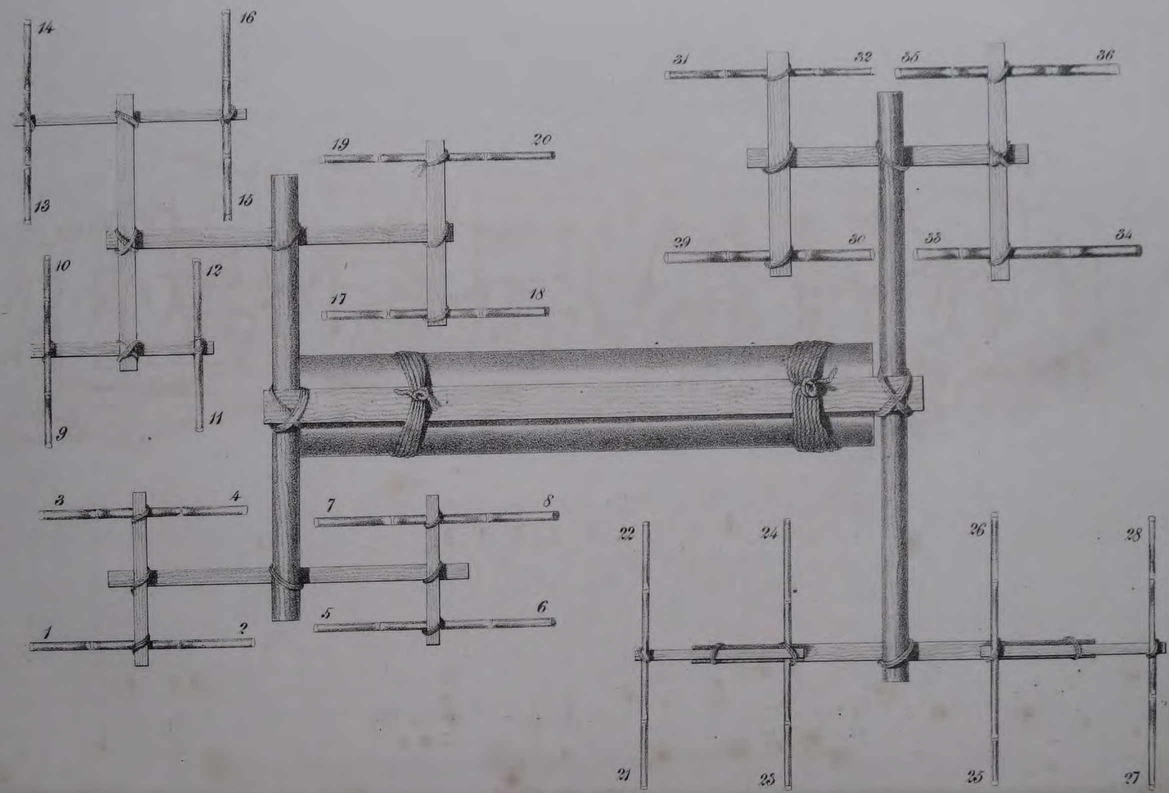
Latterly there has been no difficulty in inducing the Chinese to handle a truck and a devil carriage for the transport of large stones and timber. It was some time, however, before the use of the devil carriage could be generally introduced; because, when first applied, a Chinaman fell from the shafts, and the wheel passing over his body, crushed him to death. This circumstance, Chinese superstition, and some horror experienced by them in a literal translation of the name of the carriage, deterred them from touching it again for several months; and nearly all the large logs of timber used by me in the public buildings, and 462 large granite columns, were carried by manual labour, and the columns fixed in their positions on the buildings as described in the two accompanying spirited sketches by Lieut. Collinson, of the Royal Engineers.

Plate IV., in plan and sketch, describes the Chinese mode, by manual labour, of carrying one of the heavy granite columns used for the barracks at this station from the quarry to the building: the united power of 36 men was thus applied, to carry with ease the columns, each weighing $38\frac{1}{2}$ cwt., for about half a mile in distance.

In the same way they were carried, as shown in Plate V., up an inclined plane, to the position on the building where they were to be placed. The dispositions of the short cross pieces vary, depending on the number of men to be employed in the transport. In moving, the bearers all keep step, and change step occasionally,—at the same time removing the weight from one shoulder to the other.

The columns having thus been laid down close to the bases on which they had to be set (fig. 2), two ropes were fastened round them at a distance from their ends. To the scaffolding of the building where any column had to be raised, a China fir pole, 10″ or 12″ diameter, was attached laterally, to act as an axle, with a light platform on each side of it. To this axle, pieces of bamboo or of light fir, 5′ or 6′ in length, were transversely fixed with rattan lashings, to act as levers for the revolution of the axle. The ropes from a column having been coiled round the axle, amidst a combined application to the levers of hands, feet, bodies, lungs, and grimace, the columns were raised separately, to a sufficient height to allow of their being set into their exact required positions by the men stationed at their bases. No persuasion could induce the Chinese to use a crab capstan in this operation.

In Plate V., thirty-six men should have been represented carrying the column up the inclined plane, and twenty-eight men at work round the axle in raising the column. This drawing also represents the mat covering.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SCALE OF FEET.

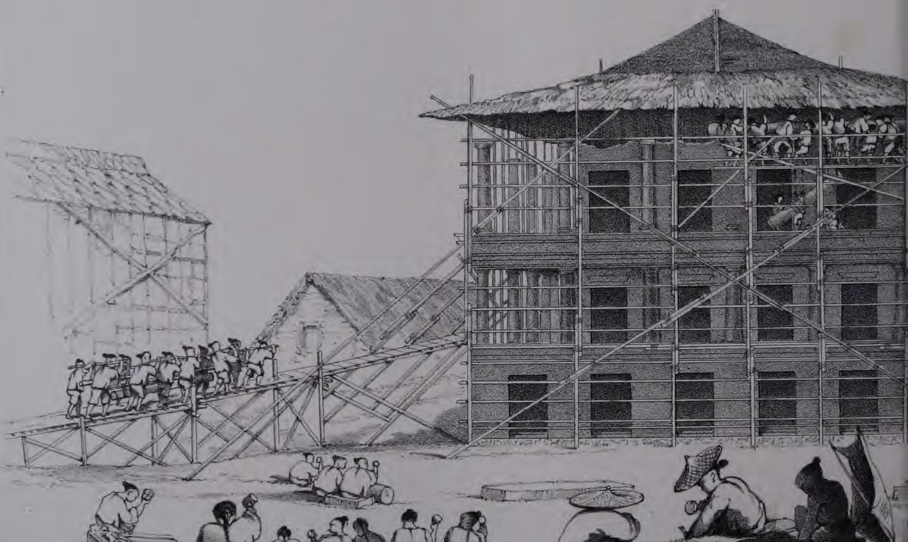
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

ELEVATION.

LIEUT. COLLINSON, R.E.
Hongkong. 1846.

John Weale, 59, High Holborn. 1849.

C.F. Cheffins, Lithog. Southampton Buildings, Holborn.



LIEUT. COLLINSON, R.E.
Hongkong 1846.

John Weale, 59, High Holborn. 1849.

C.F. Cheffins, Lithog. 11, Southampton Buildings, Holborn.

At the present day, the attention of the world is so engrossed by scientific improvements, that the power of manual labour in its simple and single state is lost sight of, and to an extent that we now look upon the Egyptian and Grecian monuments of art with amazement: our busy thoughts are puzzled to describe the mode adopted for their erection, and we almost leave the consideration with the impression, that their erection without the application of mechanical powers was impossible.

The means, however, used in the transport of heavy weights by the Chinese at this station, on the Ordnance buildings, recalls our attention to the power of manual labour in its simple state,—to the united strength of men,—and to the gigantic power derived by such unity,—pointing clearly to the feasibility, by such simple means, of undertaking even a building in rivalry of the Temple of the Sun at Heliopolis.

The method I have described of carrying a very heavy weight a distance, simply by the application of manual power, I consider might be very advantageously introduced, where mechanical means were not at command, to move with the labour of infantry a portion of a siege equipment over a difficulty in transport required to be overcome.

EDWARD ALDRICH,
Major, Commanding Royal and Superintendent Engineer.

VII.—*Campaign on the Sutlej*, 1845–6. *By Colonel* Lewis, *C. B.*, *R. E.*

PART THE FIRST.

The following is an outline of the Campaign on the Sutlej, taken from the public dispatches, by way of explaining some original documents which are here given.

It appears that the Sikh army crossed the Sutlej River on the 11th December, 1845, in great strength, and after investing Ferozepore, intrenched itself at the village of Ferozeshah, about 10 miles in advance of the former, and the same distance from Moodkee. (See Plan No. 6.)[1]

At this time, the Indian British forces were distributed at Umballa, Loodianah, and Ferozepore, extending 150 miles, bordering on the Sikh territories. When it became known that the enemy had crossed the boundary, the main force at Umballa moved by forced marches on Busseean, joined on its route by the division at Loodianah, which posts were left to the protection of a small garrison.

On the 18th the army, under the immediate command of General (now Lord) Gough, accompanied by the Governor-General of India, reached Moodkee, where it repulsed an attack of the Sikh army, and captured 17 guns.

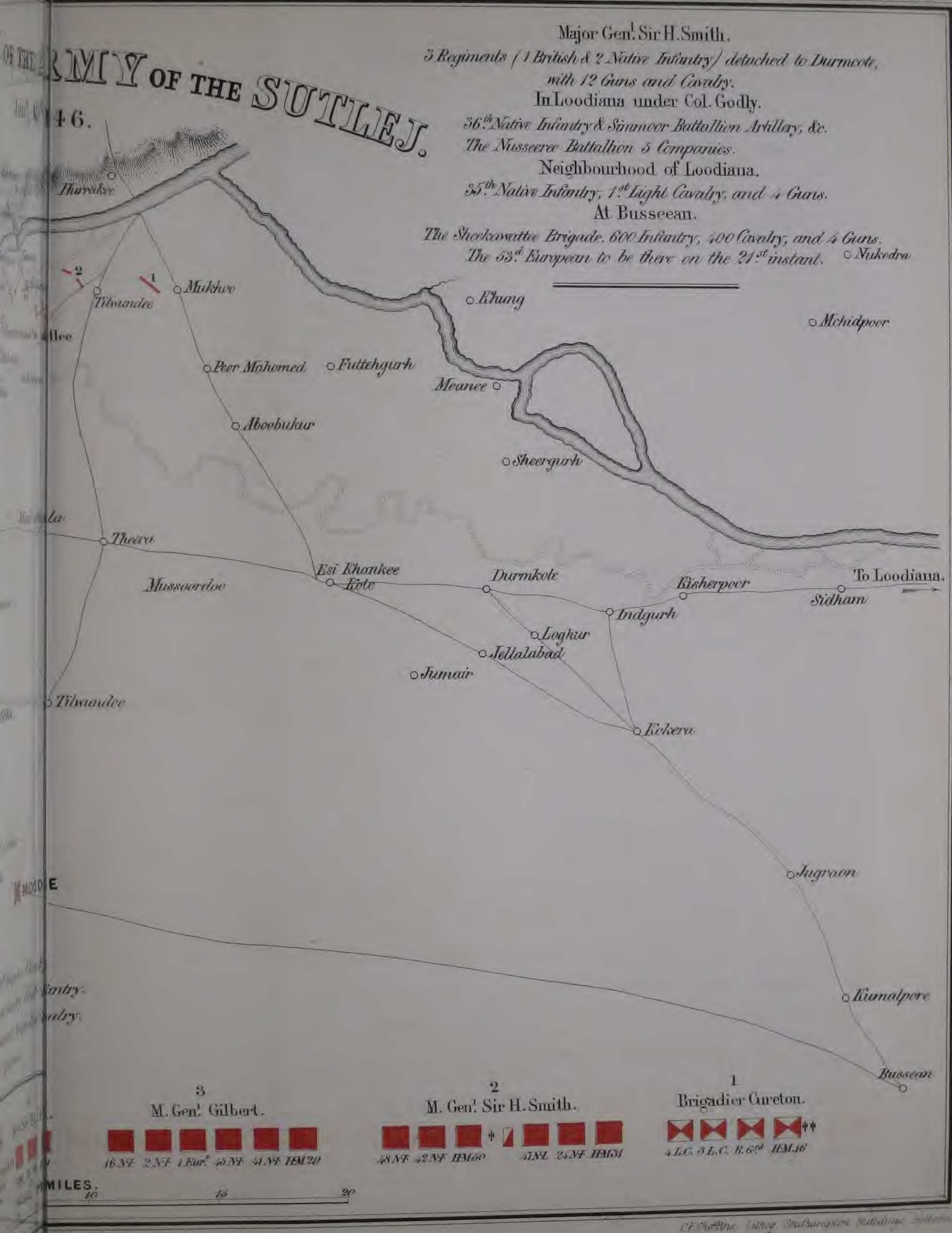
On the 21st it moved by the left on Ferozepore, having on the march effected a junction with the forces under Major-General Sir John Littler: the united armies were then as follows:

A division of infantry, under Brigadier Wallace.
,, ,, Major-General Sir Harry Smith.
,, ,, Major-General Gilbert.
,, ,, Major-General Sir J. Littler.
A division of cavalry, composed of three brigades.
Two brigades of horse artillery, composed of six troops.
One division of foot artillery of six batteries.

This combined force did not exceed 30,000 men of all arms.

[1] This and the following plans have been furnished by the kindness of the Quarter-Master-General, Sir Willoughby Gordon, G. C. B.

John Weale, 59,



Holborn. 1849.

BATTLE OF FEROZESHAH.

The combat of Moodkee, and the relief of the force under Sir John Littler at Ferozepore, both eminently successful, led to the battle of Ferozeshah, on the army continuing to advance to the intrenched position of the enemy.

The Sikhs had secured themselves in a fortified camp, with a formidable artillery, forming a sort of parallelogram a mile in length, and half that in breadth (see Plan No. 7), which was occupied by 60,000 soldiers, and 100 pieces of artillery dispersed over the intrenchments, 40 of which were heavy ordnance. The attack upon this position did not commence until late on the 21st December, when the British Indian army deployed, and was formed into two lines: the first consisted of infantry of Major-General Gilbert's division, composed of four native and two Queen's regiments; Brigadier Wallace's division, of one Queen's and three native regiments; Major-General Sir J. Littler's division, of one Queen's and five native regiments; with the artillery in the intervals between the divisions and on the flanks. The second line was composed of Major-General Sir Harry Smith's division, of two Queen's and four native regiments, and the whole of the cavalry, composed of one Queen's and six native regiments (see A A A on Plan No. 7). The whole force was divided into wings; the Commander-in-Chief took charge of the right, and the Governor-General, Lieut.-General Lord Hardinge, was intrusted with the left.

During a heavy fire from the enemy's formidable artillery, which could not be kept under by the light calibre of British Indian batteries, the whole force moved forward and stormed the intrenchments: three divisions of infantry penetrated these works, the division of Sir Harry Smith having moved up and even got possession of the inner work, the village of Ferozeshah. The division under Sir J. Littler was not able to overcome the fire of artillery to which it was exposed, and fell back in reserve; but H. M. 3rd light dragoons succeeded in penetrating the enemy's lines, and took some of his batteries, as marked E on the Plan.

The position marked F on the Plan, which Sir Harry Smith's division had secured, was found not to be tenable during the night for want of support, and accordingly that force was withdrawn.[2] At day-light on the morning of the 22nd the infantry was formed into line (see H on the Plan), supported

[2] See the unpublished Dispatch appended to this Article, given by that distinguished Officer to the compiler of this Paper.

on both flanks by horse artillery, and advanced, unchecked by the enemy's fire, and drove them rapidly out of the village and encampment, changing its front to its left, and dislodging them from their whole position. The line halted on the position marked K on the Plan, displaying the captured standards of the Khalsa artillery, having taken 70 pieces of cannon. About mid-day, Sirdar Tej Singh, who had commanded at the combat of Moodkee, brought from the vicinity of Ferozepore fresh battalions and a large field of artillery, supported by 30,000 Ghorepurras, hitherto encamped near the river. He drove in the British cavalry parties, and attempted to regain the position of Ferozeshah, as marked P, P, but was defeated. The Sirdar, however, renewed the attack with more troops and artillery, and commenced such a series of manœuvres on the left of the British Indian army as compelled it to change its front to N, N, and with his guns maintained a heavy fire of artillery, which could scarcely be answered for want of ammunition, making at the same time a demonstration against the captured village, as shown at Q, Q, on Plan No. 7.

It was now necessary to collect the nearly exhausted cavalry, and threaten both the enemy's flanks, and to prepare the infantry to advance in support, as shown on the Plan at M, N, and O. This arrangement of the British Indian forces caused him suddenly to cease his fire, and to abandon the field.

The result of the battle of Ferozeshah was the capture of the Sikh position, with 100 pieces of artillery, many standards, and the enemy's camp equipage, ammunition, and stores; and their army was now in full retreat towards the Sutlej with a heavy loss.

The loss of the British Indian army, from the advance from Busseean to the 22nd of December inclusive, was about 3000 killed and wounded.

Remarks.—The perusal of this abstract of the official documents leads to the following reflections: 1st, That the front of attack was too extended against a position armed with 100 pieces of ordnance; and consequently the left of the attacking force, which consisted of Sir John Littler's division, facing the long line of the parallelogram, was too much exposed to the formidable artillery. 2ndly, That there was no reserve, for the second line can hardly be so designated; and if the division alluded to had been in reserve in echellon, the check which occurred might have been avoided, and Sir Harry Smith's division, which captured the village of Ferozeshah, would have been supported.

These observations may be deemed hypercritical at this period, but they are made with an impression that due importance is not given to reserves in our tactical operations.

PART THE SECOND.

January, 1846.—The most interesting part of the campaign of the Sutlej is that subsequent to the battle of Ferozeshah. Up to that period, the operations had been carried on under the disadvantages of the troops, ammunition, and stores having been hastily collected from a considerable distance, when hostilities had become inevitable, and the line of attack a matter of doubt.

But during the month of January, after the Sikh army had retreated towards the Sutlej, on its defeat at Ferozeshah, and the British army was concentrated on the left bank, with its head-quarters at Bootawala, as exhibited on the Plan No. 6,[3] and the reserves of artillery, ammunition, and stores were brought up, a series of combinations took place of the highest interest, and which, under the united skill of the Commander-in-Chief and the Governor-General, effected not only the security of the Indian empire, but the conquest of Lahore.

About the middle of January, the enemy, pressed for supplies, endeavoured to draw them from his Jagheer states on the left bank of the river, in the upper Sutlej, and the Sikh forces, under Sirdar Runjoor Singh Mujethea, crossed from Philour in strength, and established a position at Baranhara, between the old and new courses of the Sutlej, threatening the city of Loodianah and the line of communications from Busseean and Rackote.

To counteract the effect of these movements, and to secure Loodianah and the communications of the British army, Major-General Sir Harry Smith's division and Brigadier-General Cureton's cavalry advanced from Jugraon; and during the march to Loodianah, the Sirdar of the Sikh army assumed the initiative, and endeavoured to intercept them in their march, first by a parallel movement, and then by outflanking them under a heavy cannonade of the Sikh artillery.[4]

These movements were frustrated by throwing the British troops in echellon of battalions, and the communication with Loodianah was thus effected; not, however, without some loss, and the capture of some of their baggage, as likewise in being separated from the troops under Brigadier-General Wheeler.

On the 21st of January, the Sikh army intrenched themselves around the

[3] Giving the position of the British forces on the 19th January, 1846.

[4] See extract from a letter from Sir Harry Smith to his sister, now published by permission.

fort of Budhowal, but being threatened on both flanks by Sir Harry Smith and Brigadier Wheeler, they abandoned this position, and retreated to the Sutlej; and in consequence of this retrograde movement of the enemy, the British troops made good their junction, reinforced by the Shekawattee brigade and H. M. 53rd regiment from Busseean.

THE BATTLE OF ALIWAL.

On the 26th, Runjoor Singh was reinforced from the right bank of the river with 4000 regular troops, 12 pieces of artillery, and a large force of cavalry; and, emboldened by this accession of strength, he advanced on Jugraon, apparently with the view of intercepting the communications of the British forces. (See Plan No. 8).

The army under the command of Major-General Sir Harry Smith, previous to the battle, consisted of the cavalry under Brigadier Cureton, and horse artillery under Major Lawrenson, formed into two brigades, commanded by Brigadiers Macdowal and Stedman; the first division of infantry of two brigades, the brigade from Loodianah, under Brigadier Godby, and the Shekawattee brigade and 53rd regiment,—forming a force of 3000 cavalry, 7000 infantry, and 34 guns.

The position of the Sikh army on the 28th January, 1846, extending from the Sutlej, (see Plan No. 8,) was secured by a circular intrenchment, by the village of Aliwal, which formed the centre, and the village of Bhoondee; the right, occupying a ridge, was strengthened by intrenchments, and about 70 pieces of artillery.

The attack commenced at day-light by the British army moving from its ground at Budhowal, the cavalry in front, in contiguous columns of squadrons of regiments, and two troops of horse artillery in the intervals of brigades; the infantry in contiguous columns of brigades, at intervals of deploying distance; artillery in the intervals, followed by two 8-inch howitzers on travelling carriages; the Shekawattee infantry on the left, and the Shekawattee cavalry on the right.

In this order the troops advanced towards the enemy a distance of 6 miles, and it was reported by spies that he contemplated moving on Budhowal or Loodianah, or upon Jugraon; but on nearing him, he appeared to occupy the position already described.

The British cavalry deployed into line, and took ground to the right and left, PLATE № 8.

showing the heads of infantry columns, and as the latter reached the hard plain, they also deployed into line. Brigadier Godby's brigade was in direct echellon to the rear of the right, the Shekawattee infantry still in rear of the left. After this deployment, the enemy outflanking the British force, the army was thrown again into columns, and moved to the right: when sufficient ground was obtained, the troops wheeled into line; there was no dust, the sun shone brightly, and the several manœuvres were performed with the celerity and precision of a field-day; the glistening of the swords and bayonets, in this order of battle, as the line advanced, forming a most imposing spectacle.

At ten o'clock on the morning of the memorable 28th January the action commenced by a heavy cannonade from the position of the enemy, when for a moment the British army had halted to bring up its right, for the purpose of carrying the village of Aliwal; and the brigades under Brigadiers Godby and Hicks made a rapid charge, carried the village, and took two guns of heavy calibre. The line again advanced, H. M. 31st foot and native regiments contending for the front; and the battle became general. Whilst these operations were going on in the centre, Brigadier Cureton moved to the right with a brigade of cavalry, and drove the Sikh horse back upon their infantry; and a second gallant charge was made on the right by the light cavalry and body guard. The left of the British army, under Brigadier Wheeler, moving at the same time with H. M. 50th regiment, the 48th native infantry, and Sirmoor battalion, supported by Brigadier Wilson, with H. M. 53rd regiment and the 30th native infantry, attacked the enemy's right, and drove back the Aieen troops, called Avitabile.

The enemy, well driven back on his left and centre, endeavoured to hold his right to cover the passage over the river, and he strongly occupied the village of Bhoondee. Two squadrons of H. M. 16th lancers charged a body to the right of the village, supported by the 3rd light cavalry, and drove every thing before them; and Her Majesty's 53rd regiment carried the village, supported by the 30th native infantry. The largest gun in the field and seven others were captured; and the two troops of horse artillery, under Major Lawrenson, pursued the flying infantry, committing great havoc. About 800 or 1000 of the retreating force rallied under the high bank of a dry nullah, and opened a firing from below, but from this they were dislodged by the 30th native infantry, exposing them to the fire of 12 pieces of artillery; and

H. M. 53rd regiment moved forward in support by the right of the village of Bhoondee. (See Plan No. 8.)

The battle was now won, the British troops advancing on one common focus,—the passage of the river; the enemy was precipitated in disordered masses on the ford and boats; the 8-inch howitzers were brought to play upon the boats, when the *débris* of the Sikh army appeared on the opposite bank of the river, flying in every direction, though an attempt was made to cover the retreat; but after a furious cannonade from the whole of the British artillery, the enemy quickly disappeared.

The result of this victory was the capture of 67 pieces of ordnance and 40 swivel or camel guns, with a large quantity of ammunition and stores, grain, baggage, and camp equipage, and the destruction of the greater part of the Sikh army under Sirdar Runjoor Singh Mujethea. The loss of the British forces in killed, wounded, and missing, did not exceed 600 men and 353 horses.

Remarks.—The battle of Aliwal may be divided into the following tactical operations,—the advance, the attack on the enemy's left and centre, the attack on their right, when they rallied about Bhoondee, and their final defeat, forming an excellent example of the combinations of artillery, cavalry, and infantry, or "la tactique des trois armes,"—from which may be derived an admirable lesson in the art of war, forming a series of echellon movements of the British army from its breaking ground to advance until the final retreat of the enemy, bringing each arm into action as wanted, without exhausting either; so that at the close of the battle, infantry, cavalry, and artillery were equally available as at the commencement. This may be attributed to the skill of the Commander, exercising his experience in the four quarters of the globe, when intrusted for the first time with the command of a considerable army, composed of such excellent materials as that which gained the *Battle of Aliwal.*

The immediate consequence of this victory was the evacuation, by the Sikh garrisons, of all the forts hitherto occupied by detachments of Lahore soldiers on the left bank of the Sutlej, and the submission of the whole territory to the British Government, except a formidable tête du pont and intrenchments in front of Sabraon, supported by the position on the right bank, which the Sikh army had held since their defeat at Ferozeshah, on the 21st December, 1845.


Batteries

The month of January was spent in operations on the upper Sutlej; the forces under under Major-General Sir Harry Smith joined the main army on the 8th of February, 1846, and during the former period, the General Commander-in-Chief directed the advance of the siege train from Delhi; and the first portion of this equipment, with the reserve ammunition for 40 field guns, reached the camp, and the brigades which had been detached from the main army for the operations in the neighbourhood of Loodianah rejoined him. Thus reinforced, the distinguished officers in charge decided upon attacking the Sikh army, and dislodging it from the left bank of the Sutlej, and commencing operations in the Lahore territory.

BATTLE OF SABRAON, 10TH FEBRUARY, 1846. (SEE PLAN NO. 9).

Description of the position and forces of the Sikh army.—The tête du pont covering the bridge over the Sutlej extended itself in front of Sabraon in a semicircular form, about 2 miles in length, broken into redans and re-entering angles, and with three inner retrenchments for musketry. The works of the outer line were armed with 67 pieces of artillery, placed in 27 batteries with considerable care, some of them blinded upon a profile varying from 3 to 6 feet above the level of the ground,—the materials for the parapets forming the ditch, which scarcely created an obstacle; but immediately in rear of these batteries were constructed cavaliers for musketry, which gave considerable strength to the fortified position. The Sikh army had several batteries on the right bank of the Sutlej, armed with from 40 to 50 pieces of artillery, commanding and flanking the tête du pont and the intrenchments on the left bank. These were manned by 35,000 of the best of the Khalsa troops, with 200 zoomburucks, or camel swivels. (See Plan No. 9.)

Strength and disposition of the attacking force.—Previous to the action, three divisions of infantry and one division of cavalry of three brigades, with a division of artillery, forming a force of about 30,000 men of all arms, were distributed in the following manner: the heavy and field artillery were put in position on an extended semicircle around the works of the Sikhs, marked c, c, c, on Plan No. 9. Two brigades of infantry, under Major-General Sir R. Dick, were placed on the extreme left: the 6th and 7th brigades, under Brigadiers Wilkinson and Stacy, moved from the village of Kodeewalla, supported by the 5th brigade, under Brigadier the Hon. T. Ashburnham.

In the centre, Major-General Gilbert's division was deployed for attack, its right resting on the village of Little Sabraon. Major-General Sir Harry Smith's division was formed near the village of Guttah, with the right thrown up towards the Sutlej, marked by the letters B, B, B, B, on the Plan. Brigadier Cureton's cavalry threatened by feigned attacks the fort at Hurreekee, and the enemy's horse, under Rajah Lall Singh Misr, on the opposite bank of the river; Brigadier Campbell's cavalry taking an intermediate position in rear between Major-General Gilbert's right and Major-General Sir Harry Smith's left; and Brigadier Scott's cavalry was held in reserve on the left of the whole, ready to act as circumstances required, under the immediate orders of Major-General Sir J. Thackwell.

The assault commenced at half-past six o'clock on the morning of the 10th February, by a heavy cannonade from the whole of the British artillery, forming a well-directed fire of 100 pieces of ordnance, composed of heavy iron guns, mortars, howitzers, and field batteries, aided by a rocket battery, all of which made admirable practice, and their effect was severely felt by the enemy. At nine o'clock Brigadier Stacy's brigade, supported on either flank by Captains Horsford's and Fordyce's batteries, and Lieutenant-Colonel Lane's troop of horse artillery, moved to the assault in admirable order, when the latter, at the distance of 300 yards, opened upon the heavy guns of the Sikhs. Notwithstanding the regularity, coolness, and scientific character of the assault, which Brigadier Wilkinson supported, so hot was the fire of cannon, musketry, and zoomburucks, kept up by the Khalsa troops, that it seemed for some moments impossible that the intrenchments could be won under it; but soon persevering gallantry triumphed, and the whole army had the satisfaction to see Brigadier Stacy's soldiers drive the Sikhs in confusion before them within the area of their encampment. H. M. 10th foot, under Lieutenant-Colonel Franks, now for the first time in this campaign brought into serious contact with the enemy, greatly distinguished themselves: this regiment never fired a shot until it had got within their works. The onset of H. M. 53rd foot was as gallant and effective. The 43rd and 59th native infantry, brigaded with them, emulated both in cool determination.

At the moment of this first success, Brigadier the Hon. T. Ashburnham's brigade was directed to move in support, and Major-General Gilbert's and Sir Harry Smith's divisions to throw out their light troops to threaten the works, aided by artillery. As these attacks of the centre and right commenced, the fire of our heavy guns had first to be directed to the right, and then gradually to cease; but at one time the thunder of full 120 pieces of ordnance reverberated in this mighty combat in the valley of the Sutlej.

As it was seen that the weight of the whole force within the Sikh camp was likely to be thrown upon the two brigades which had passed the trenches, it became necessary to convert into close and serious attacks the demonstrations with skirmishers and artillery of the centre and right, and the battle raged with inconceivable fury from right to left. The Sikhs, even when at particular points their intrenchments were mastered with the bayonet, strove to regain them by the fiercest conflict, sword in hand. Nor was it until the cavalry of the left, under Major-General Sir J. Thackwell, had moved forward and ridden through the opening in the intrenchments made by the Sappers, in single file, and re-formed as they passed them, and the 3rd dragoons galloped over and cut down the obstinate defenders of the batteries and field-works, and until the full weight of three divisions of infantry, with every field gun which could be sent to their aid, had been cast into the scale, that victory finally declared for the British.

The fire of the Sikhs first slackened, and then nearly ceased; and the victors then pressing them on every side, precipitated them in masses over the bridge and into the Sutlej, which a sudden rise of seven inches had rendered hardly fordable. In the efforts of the enemy to reach the right bank through the deepened water, they suffered severely from the horse artillery, and hundreds upon hundreds were drowned in attempting the perilous passage. The determined hardihood and bravery of the battalions of Ghoorkhas, the Sirmoor and Nusseeree, were conspicuous wherever they were opposed to the Sikhs; and although of small stature, they had an indomitable spirit, and vied in ardent courage in the charge with the grenadiers of our own nation, and, armed with the short weapon of their mountains, were a terror to the enemy throughout this great action. (See Plan No. 9.)

The result of the battle of Sabraon was the capture of 67 pieces of ordnance, 200 zoomburucks, numerous standards, and vast munitions of war; the loss of 10,000 men and many chiefs of the Khalsa army; the passage of the Sutlej, and the conquest of the Lahore territory. The killed and wounded of the British forces amounted to 2383 of all arms.

CONCLUSION.

In giving this abstract of the public dispatches describing the campaign of the Sutlej, care has been taken to preserve facts as recorded in them, amalgamated in one uninterrupted narrative; and as it does not appear that the official accounts have ever been accompanied by plans, it is conceived that this Paper will excite an interest, although nearly three years have elapsed since the occurrence of the brilliant achievements in the Punjaub.

Now that our Indian empire is extended to the Indus, and to prevent the necessity of further quixotic expeditions beyond, the consideration of establishing several fortresses of the first class on that mighty river, on which we have established an uninterrupted navigation, is worth the attention of the Indian Government; and the cost of erecting strong fortified posts at Kurachee, Bukkur, Mittun, and at the passes of Dera Ghazee Khan, Dera Ismael Khan and Attock, would not exceed one-tenth the amount of an expedition into Cabool.

G. G. L.

18th October, 1848.

Unpublished Dispatches of Lieut.-General Sir Harry Smith, G. C. B.

Head-quarters of 1st Division of Infantry, Army of the Sutlej,
Camp, Sooltan Khan Wallah, December 24, 1845.

SIR,

I have the honour to report, for the information of His Excellency the Commander-in-Chief, a detail of the operations of the 1st division of infantry under my command in the action of the afternoon of the 18th instant, in front of Moodkee.

The troops were most suddenly turned out on the advance of a large portion of the Sikh army. The 2nd brigade of infantry, consisting of Her Majesty's 50th, the 42nd and 48th corps of native infantry, I directed to deploy into line, and to advance in support of the cavalry and artillery. This brigade was immediately hotly engaged. Major-General Sir Robert Sale, C. B., advanced at the head of the 42nd regiment N. I., and received a wound of which he has since died. As a friend, I deeply regret him; as a soldier, Her Majesty has lost a noble one: his gallant services need no comment from me.

Brigadier Wheeler, C. B., was at the head of the 48th regiment N. I. His horse being shot, he was himself cut down, and severely wounded in two places by sabre cuts.

The service was thus deprived of one of the most able of its officers. I trust, however, this is only for a short period.

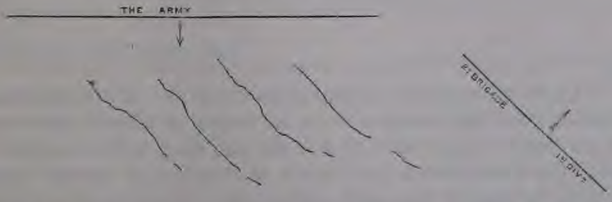
I remained generally with Her Majesty's 50th regiment (as the right flank of the army was much exposed), upon whom the brunt of the action on the right fell: a long advance in line, under a heavy fire of shot, grape, and musketry, caused it, I regret to say, a severe loss both of officers and men.

A battery of six guns in one part of the field, and a howitzer in another, were most gallantly carried by the 50th and the 48th N. I., and the gunners bayoneted at their guns, to which they stood, and died in the bravest manner.

Captain Swinley's troop of horse artillery, with the usual gallantry of this corps, rendered most efficient support upon my right.

The 1st brigade, under Brigadier Bolton, C. B., consisting of Her Majesty's 31st regiment and the 47th N. I. (the 24th regiment of N. I. being absent on escort duty), were moved forward far to the left, and under His Excellency's immediate eye. A battery of six guns was most gallantly stormed and carried by the corps, at the head of which Brigadier Bolton received a very severe wound. The command of the brigade devolved upon Lieut.-Colonel Hicks, 47th N. I., whose report, together with that of Lieut.-Colonel Ryan, Her Majesty's 50th regiment, I herewith enclose.

In the dusk, amounting almost to total darkness, it appeared to me that that part of the army under His Excellency's immediate direction drove the enemy across my front late in the evening, which exposed his flank to my fire, so as to cause him extraordinary loss. The firing ceased some time after dark, and I found that the 2nd brigade of my division had, in this rapid advance, crossed the front of the army, and, when halted, was on the left of the line, and facing to the rear, thus:



It is gratifying to know that not a shot from the line ever came into the ranks of my division, such was the rapidity of the advance of this brigade.

In an action almost in the dark, it is difficult to distinguish individuals; yet, early in the conflict, I saw enough of Brigadier Wheeler to assure me that the high character this officer has attained by long service is well merited, and that his wound deprives His Excellency of one of his most able officers.

The veteran Lieut.-Colonel Ryan, on whom the command devolved, showed his bravery and experience conspicuously; while the cool and determined gallantry of Lieut.-Colonel Petit, commanding Her Majesty's 50th regiment, inspires me with a high opinion of him. He *must* rise in his profession; as well must also Captain Palmer, of the 48th N. I.

I and my troops and divisional staff were young in association; but the activity of Captain Lugard, Her Majesty's 31st regiment, Deputy Assistant Adjutant-General, and Lieutenant A. S. Galloway, 3rd light cavalry, Deputy Assistant Quarter-Master-General, proved to me that the selection of these officers for their respective appointments was most fortunate; and that Her Majesty's 50th regiment still maintains the celebrity of its character and distinguished services. I feel convinced that in a protracted campaign the native infantry troops would be as efficient as they have hitherto invariably proved.

The veteran 48th N. I., for so many years ably commanded by Brigadier Wheeler, while they deeply felt his loss, were inspired with ardour again to meet that enemy which had caused it.

(Signed) H. G. Smith.

To the Adjutant-General.

Killed . . .	5 officers . . .	73 men.
Wounded . .	20 ,, . . .	319 ,,
Missing . . .	0 ,, . . .	19 ,,
	25	411

Strength of the 1st division:

105 European officers. 42 native officers. 3250 men.

Head-quarters, Camp, Dec. 23, 1845.

Sir,

I have the honour to record, for the information of His Excellency the Commander-in-Chief, the operations of the 1st division of infantry under my command in the brilliant victory obtained over the Sikh army in the afternoon of the 21st inst. The Commander-in-Chief placed this division in reserve during the advance upon the enemy's intrenched position: the 1st brigade to the immediate right of our mass of artillery,—the 2nd brigade, in a similar manner, to its left, at a distance of 350 yards. My division thus disposed of, the army advanced, and I gave orders to Brigadier Hicks, of the 1st brigade, to continue to move until he received further orders from the Commander-in-Chief. I joined the 2nd brigade. By this time General Littler's division was well in action, and the fire upon the left of the main attack very heavy, when Lieutenant-General Sir H. Hardinge ordered the 2nd brigade to move up rapidly into the front line, which at the moment reeled under the enemy's galling fire from behind his intrenchments and numerous cannon. In establishing this brigade in its regular advance in line, some confusion in the front occurred by other corps falling back upon it and impeding its advance. The front once clear, the steadiness and rectitude of its advance could not be exceeded, when Major Broadfoot, C. B., galloped to me to say four battalions of Avitabile's corps were about to turn my left flank, and precipitate themselves between my left and Littler's right: I therefore changed the direction of my advance as far as practicable, during which these four battalions made a furious onslaught upon us with a storm of musketry, aided by cannon and grape, &c., which I have rarely seen surpassed.

The brigade opened its fire in return. The weight of the attack was upon H. M. 50th regiment, which literally staggered under the storm. Major Somerset, Military Secretary to the Governor-General, was struck down by two bullets. My Aide-de-Camp was wounded, his horse killed under him; officers and soldiers falling fast; when I ordered the brigade to charge, which was gallantly obeyed, and Lieutenant-Colonel Petit headed the 50th regiment into the enemy's intrenchments, fighting almost hand to hand.

This fierce attack of the enemy being thus nobly repulsed, I continued to advance in line, in perfect order, until impeded by the enemy's tents, when the whole broke, and in a mass of undaunted British soldiers, rushed, pell-mell, forward, bearing every thing before them until we reached the mud-walled village of Ferozeshah, when the enemy attempted to rally, and compelled me to collect my troops. I speedily seized this village, filled with infantry, cavalry, and horses richly caparisoned: many of the enemy were slain, and many surrendered themselves prisoners: the colours of Her Majesty's 50th regiment, gallantly borne forward by Brevet-Captain Lovet and Ensign De Montmorency, were planted on the walls of the head-quarter village of the enemy's army, and well in the rear of his intrenchments and numerous cannon.

By this time many detachments belonging to regiments composing the left of the main attack, some of H. M. 9th, of the Hon. Company's regiments and 1st Europeans, and many individual officers and soldiers of native corps, had joined me on the right of the village. It was now dark, and I ordered every one to halt and form; but such was the excitement and exultation for the moment, that it was totally impossible to establish any thing bordering on regularity. This I disregarded at the time, feeling convinced the victory was pushed equally forward upon my right and left. As this excitement subsided, I endeavoured with some success to collect the troops, and form in line in a semicircle around the front of the village. I could hear nothing but the shouts of the enemy; and it became evident that the support anticipated on my right and left had not been pushed forward, and that with the scattered troops, amounting to between 2 and 3000 men of different regiments, besides the 2nd brigade, I now occupied an isolated position in the very centre of the Sikh army. It was evident too that the attack on the enemy's left and main position in the centre had been successful, though not pushed forward; and it was equally evident that the attack upon his right had failed, as from his intrenchments and cannon a continued fire was kept up during the dark. Scarcely had I succeeded in a formation in front of Ferozeshah, when rather a sharp attack was made on my right. The enemy, most fortunately, was prevented in the darkness from pushing the advantage gained. I contracted my position, and re-occupied my right. The enemy continued to approach on all sides, and kept up a continued fire of cannon, camel pieces, and musketry, most destructive in its effect. My position was cut off. I had no intimation of the position of the army whatever, or any hope of reinforcements. The enemy had brought a gun to bear upon my immediate rear, from which he kept up a continued fire of grape. He was firing and shouting, beating the French 'pas de charge,' all around us. Major Griffin, of the 24th native infantry, was killed; Major Hull, a most noble officer of the 16th grenadiers, mortally wounded; my Deputy Quarter-Master-General, Lieut. A. S. Galloway, wounded in two places; also many others: almost every officer's horse was killed; the troops much excited, although H. M. 50th regiment, and a small detachment of H. M. 9th, under Major Barnwell, were well in hand, and to be depended on. Having thus maintained this isolated post until between 2 and 3 o'clock in the morning, and having occupied the attention of the enemy all night, I saw that unless I at once withdrew, the troops were compromised. I therefore, in perfect silence, commenced my march, which the enemy, from the noise of his own fire, did not discover, and moved on the line by which we attacked, and in about two miles fell in with the wounded men of H. M. 62nd regiment and others collected, whom I brought off. They knew nothing of the army, and I continued my march in the same direction until large bivouac fires guided me to a brigade of cavalry and numerous stragglers of the army. With them, at day-break, I commenced my march, guided by Christie's horse, re-established my communication with head-quarters, and received orders from the Commander-in-Chief to move up rapidly in support of the attack about to commence on that part of the enemy's position from which he had not been dislodged the previous evening, and which I well knew His Excellency would make, and which increased my anxiety to join him.

The operations of the 1st brigade of my division having been conducted under Brigadier Hicks, I herewith enclose his report. His Excellency witnessed the charge of H. M. 31st on the enemy's intrenchments on the morning of the 22nd inst., which so mainly contributed to the complete rout of the enemy, and the achievement of this glorious battle, adding fresh lustre to Her Majesty's and the Honourable Company's arms.

It would not be just if I were not here to mention those individuals whom I observed most active and intrepid, Brigadier Ryan and his Major of Brigade, Captain

O'Hanlon: the cool intrepidity of Lieut.-Colonel Petit surpasses all praise, while the conduct of the officers and soldiers of the 50th regiment bore down every obstacle, and their colours were planted on the walls of the head-quarter village of the enemy's army, Ferozeshah. Two of his standards add to the trophies of this victory and the prowess of the 50th regiment. Another standard was also taken by H. M. 31st regiment, and the number of cannon we passed in the advance showed well the greatness of the victory achieved. Many of the native troops gallantly and most emulously contended for the advance with H. M. troops; and when we regard the paucity of officers in the native corps,—one regiment in the 1st division having only two officers,—we are led to the conclusion that innate bravery alone conducts them to the front. The 48th regiment, under Captain Palmer, distinguished itself. I also observed, with satisfaction, detachments of the 16th grenadiers, under the command of Major Hull, whose assistance, before he received his mortal wound, I must ever appreciate most highly;—of the 26th native infantry, under Captain Taylor; and several others, whose names I have not succeeded in obtaining. Lieutenant Mainwaring, of the Commissariat, who joined, and attached himself to the troops under my command, is a gallant fellow. To Captain Lugard, my Deputy Assistant Adjutant-General, the service is deeply indebted: he received two wounds without quitting the field, and is now in the performance of his duty. Lieutenant Galloway, my Deputy Quarter-Master-General, is an officer of no ordinary promise,—cool, intrepid, and active. I beg His Excellency's attention may be drawn to the merits of these distinguished officers. To my Aide-de-Camp, Lieutenant Holdich, of H. M. 80th regiment, I am much indebted; and the gallant exertions of Ensign Hardinge, son and Aide-de-Camp to the Governor-General, at the moment of the attack of Avitabile's battalions, were as conspicuous as gallant.

In Brigadier Hicks the service has a very able and excellent officer; and to his Major of Brigade, Captain Garvock, of the 31st regiment, I am much indebted. Major Spence, commanding H. M. 31st, is an officer of great promise: the manner in which he, in three successive victories, led this gallant corps to their achievement, merits His Excellency's most favourable consideration. Captain Pott, commanding the 47th regiment N. I., did his duty ably. When every officer and soldier gallantly and fearlessly contributes to such victories, those only can be more particularly named whom accident brings under notice. I conclude, therefore, by expressing the grateful sense I entertain of His Excellency's having placed me in the command of a division which I trust may be firmly established in the estimation of the Commander-in-Chief, and regarded by His Excellency as having contributed to the late brilliant victories.

In the course of these operations I have been much associated with the artillery of this army, and I should be wanting in justice if I did not venture to record my most unqualified opinion of its bravery, of its meritorious zeal, and ardent desire to contribute its utmost to that success which has recently attended our army. I especially wish to notice Brevet-Major Brinde.

I annex a return of the killed and wounded, as also a list of the officers and the second in command of corps. It has occurred to me that Lieutenant-Colonel Byrne, who commanded H. M. 31st regiment in the action of the 18th instant, in which he was severely wounded, has not been mentioned by me in my previous report: I beg, therefore, to draw His Excellency's attention to the merits and bravery of this officer.

I have the honour to be, Sir,

Your obedient and honoured Servant,

H. G. SMITH,

Major-General, Commanding 1st Division.

RETURN OF KILLED AND WOUNDED:

Killed . . .	10 officers . . .	125 men.
Wounded . .	17 ,, . . .	328 ,,
Missing . .	0 ,, . . .	97 ,,
	27	550

Strength of the 1st division:

104 European officers. 54 native officers. 4037 men.

Two brigades: all my staff killed or wounded. Total, both days, 52 officers and 991 men.

Extract from a Letter written by Major-General Sir H. G. Smith, G.C.B., to his Sister, Mrs. Sarjant, dated Simla, May 15, 1846.

"The Houses of Parliament being in their seats, may vote me thanks: they have done so for many battles of smaller military calibre; and in political importance none ever exceeded it. All India was at gaze, and ready for any thing;—our army, truth must be told, most anxious;—the enemy, alarmingly and exultingly regarding himself invincible, as the *bold* and *most able* and *energetic move* of Runjoor Singh, with his whole force throwing himself between my advance from Jugraon, *viâ* Budhowal to Loodianah, most fully demonstrated. It is the most scientific move made during the war,—whether by accident or design,—and had he known how *to profit* by the position he had so judiciously occupied, he would have attained wonderful success. He should have attacked *me* with vigour, for his force was, as compared to mine, *overwhelming*;—then turned about upon the troops at Loodianah, beaten them, and sacked and burnt the city;—when the gaze I speak of in India would have been one general blaze of revolts. Does the world, which argues upon my affair at Budhowal, suppose I was asleep, and had not in clear perspective a full view of the effect which such success of the enemy would have had upon the general feature and character of the war?—our battering train, an immense treasure, our ammunition, &c., &c., not ten miles from me, occupying a line of road ten miles in length.

"Such is the outline;—now to descend somewhat into the minutiæ of detail. I was sent with one brigade of infantry, a regiment of native cavalry, and 100 irregular horse, and six 9-pounder guns, to reduce two fortresses, Dhurmkote and Futtehgurh. The latter was evacuated on my approach; the former, after a march of 26 miles, was reduced by a few round shot, and I occupied it by two companies. The day following, I was instructed that a brigade of cavalry and two troops of horse artillery would join me, with twelve 6-pounder guns; that I was to move on Jugraon, where I might possibly lay hands upon Her Majesty's 53rd regiment, moving up from the rear upon another line of road, ten miles distant from me, *viâ* Busseean; and that in three or four days I might be joined by the Shekawattee brigade,—a sort of irregular force with three or four officers, four guns, 300 infantry, 400 cavalry;—that the object of my force was to preserve our line of communication by Busseean, and to get into communication with the force at Loodianah, and preserve the city from inroad. Jugraon, my position, was distant from Loodianah by the direct road, *viâ* the little fortress of Budhowal, 25 or 26 miles. I was to establish a communication with Loodianah, and assure it of my support. I did so, and the pressing requests to afford that support by the actual presence of my force could not be more urgent; while, on the other hand, I was directed by the strongest instructions from the Governor-General and Commander-in-Chief to lose no time in repulsing Runjoor Singh, who would daily receive reinforcements if left unmolested, while the 'prestige' of our arms would daily also tarnish. ALL accounts agreed, when I reached Jugraon on the 20th, that the enemy was still at 'Baranhara,' 30 miles *from me* between Loodianah and Philour, a fortress of the enemy on the right bank of the Sutlej, under cover of which he had crossed and perfected his invasion; but that the fortress of Budhowal having been abandoned by the troops of a chief in amity with us, had been occupied by a small garrison of the enemy, and that he had near it some two or three hundred horse: he also possessed a fortress called Gungrana, regarded as very strong, to my right (that is, its parallel), about 10 miles from Budhowal into our interior, where there was also cavalry. I did get hold of the 53rd regiment on the evening of the 20th, the day I arrived at Jugraon: my force therefore stood thus,—18 guns, 1 regiment, 16th lancers, English cavalry; 1 regiment native light cavalry; 1 regiment of irregular horse; 2 regiments of British, 31st and 53rd, and two very weak regiments of native infantry, 24th and 47th. At Jugraon was a very tenable fortress, occupied by the troops of a friendly Rajah. In times of war and doubtful success, friendship is precarious. I therefore occupied the fortress, or rather its citadel, by two companies of my native infantry, and resolved to march as soon as the moon was up, viz. half-past twelve, on Loodianah, leaving Budhowal to my *right*, by the best, shortest, and direct road, and I ordered all baggage to remain behind, under the protection of the fort of Jugraon, which consisted of the WHEEL carriage transport.

"Meanwhile I dispatched, every two hours, to the officer who commanded at Loodianah, instructions of these my intentions, and my orders where he was to meet me with his force of four horse artillery guns, an excellent and strong regiment of native cavalry, and four good and fresh regiments of native infantry, all the while believing the enemy's force to be at Baranhara, thirty miles from me, but only seven from Loodianah. My order of march was in writing, with instructions for the baggage, and detail of its guard; and I sent them on the afternoon of the 20th to all the officers in command, and marched with most regular order at the hour appointed, with the desire to leave Budhowal to my right, and *not* move by the interior line, viz. between Gungrana and Budhowal, two fortresses in the occupation of the enemy, distant from my flanks only five miles;—hence my march subject to double interruption;—and the large force nearly equal to mine was to have approached me from Loodianah to within three miles of Budhowal on its own side, on a strong hill and position I well knew, Sonnait. The natives here were most hostile. It is an axiom, and a very just one in the conduct of war, 'distant combinations are not to be relied on.' Hence, although I calculated upon the combination, I did not wholly depend upon it, but adopted my own measures for advance with caution and circumspection, trusting rather to *my own* and *immediate resources.* When I had marched some sixteen or eighteen miles in the most perfect order of advance to within two miles of Budhowal, as day dawned I received a communication from Godby that the enemy had marched from Baranhara, and was encamped around Budhowal with his whole force, and from some villagers I ascertained that the enemy at Budhowal had received *considerable reinforcements.* Thus I had one of two alternatives, viz. to move on, leaving Budhowal to my right, and most probably the moving Sikh army on my left,—in other words, to force my passage,—or leave Budhowal to my left, and make a détour towards Gungrana. I changed my order of march, and proceeded with every precaution, leaving the fort of Budhowal at least two miles to my left, my troops in order of battle, by wheeling into line to their left, if required. We had observed rockets firing, as if for signals, several times during our night march; and we discovered the enemy at broad day-light preparing to interrupt my newly adopted line of march, viz. leaving Budhowal to my left,—his most ample preparation, as I afterwards discovered, having been made for my reception as I had originally intended to move,—so perfect was his information; and upwards of forty pieces of cannon pointed on the direct road. As soon as the enemy had discovered I had changed my line of march for the relief of Loodianah, he immediately attempted to interrupt my force by moving parallel to my column through a line of villages affording him cover and protection, and equally by good roads facilitating his march; while I was compelled to move in order of battle over ploughed fields of deep sand. Hence the head of the enemy's column, principally a large body of cavalry, rapidly outflanked me a mile at least, and his rear of guns and infantry equally so. He with great celerity brought to bear upon my troops a considerable number of guns, some of very heavy metal. Our cavalry moved parallel with the enemy, and protected from the fire of his guns by a low ridge of sand hills. My 18 guns I kept together, close in rear of the cavalry, for the purpose of opening a fire on the enemy, and to check his advance; thereby attracting his attention so soon as the fortunate moment which I saw approaching arrived. This fire had a most auxiliary effect, which I continued for some ten minutes, creating slaughter and confusion in the enemy's ranks. The enemy's cannonade upon the column of infantry had been previously to this furious. I had reinforced the baggage guard, and sent orders that it should close up and keep well on the reserve flank, and as much ahead as possible. A few round shot fell among the camels; the drivers, many of them, abandoned their animals: our own followers, and the hostile villagers of the neighbourhood, plundered a part; little of it fell into the hands of the enemy's soldiers, as the column moved on under this furious cannonade, especially upon the rear of the infantry. The enemy, with a dexterity and quickness not to be exceeded, formed a line of seven battalions directly across my rear, with guns in the intervals of battalions, for the purpose of attacking *my* column with *his* line,—a very able and well-executed move on his part, which rendered my position critical, and demanded nerve and decision to evade the coming storm. I would willingly have attacked this line, and formed a part of the 31st regiment as a base, when, so deep was the sand, and so fatigued were my men, that I was compelled to abandon the project. I therefore, under this fierce cannonade, changed front on the centre of the 31st regiment and of the 53rd regiment, by a difficult movement on parade even, a countermarch on the *centre* by wings. Then became conspicuous the majesty of discipline and bravery. This was executed as accurately as at a review. My native regiments were very steady, but these I continued in column. I now directed the infantry to march on Loodianah in echellon of battalions, ready to receive the word 'Halt—Front;' and when they would thus confront the enemy's line, if he advanced, and the cavalry in echellon of squadrons, the three arms mutually supporting each other,—the guns in rear of the cavalry. The movement was so steady that the enemy, notwithstanding his overwhelming force, did not attack, but stood amazed, as it were, fearing to quit his stronghold of Budhowal, and aware that the junction of my force with that of Loodianah was *about to be accomplished.*

"Hearing nothing from Loodianah astonished me, I admit. I had reason to hope some of my two-hourly dispatches had reached it; and when at day-light I changed the direction of my march, the enemy having anticipated me, I sent Lieutenant Holmes with a party of irregulars, cautioning him to look as sharp to his right, on account of Gungrana, as to his left. I soon after sent off Lieutenant Sweetenham, 16th lancers, and in a short time afterwards I sent off Lieutenant Baird Smith, of the Engineers. All these officers reached their destination. From the repeated and urgent requests made by Colonel Godby that I should advance to his relief, from his *then knowledge* that the enemy had anticipated me, I had every reason (supposing he had received no positive information of my march from Jugraon or my orders) to expect some co-operation or demonstration in my support, as I moved towards him. On the contrary, my first messenger found his troops only turning out, he having only just received my instructions, and his force did not move off until the firing had commenced, about half-past seven or eight, at a distance of between eight and nine miles,—verifying the axiom, 'distant combinations are not to be relied on.' The natural expectation, too, of some move towards me cramped my manœuvres; for had I swerved from this line, on which I expected assistance, that force would have been compromised, and in the power of the enemy's weighty assault. The reinforcement of four guns, a strong and fresh regiment of cavalry, and four regiments of fresh infantry, is a powerful reinforcement to a large army;—to me it was nearly one-half of the whole.

"Decision, coolness, and determination effected the junction and relief of Loodianah, while it cut off the enemy from his line of communication with Philour, under which fortress he had crossed the Sutlej. A want of water in a position near the enemy compelled me to encamp in front of Loodianah, while I established my outposts close upon him, and made frequently strong patroles up to his position, intending, if he dared attempt to interrupt our line *viâ* Busseean, (which I did not, although I closely watched him, anticipate, so close *was* I upon him, and the fortress of Jugraon before him,) to move on *coute qui coute*, and attack under any circumstances. Indeed, my combined force would have well enabled me to do so, had I come up with him on the march, and of course out of his intrenchments. Meanwhile the Commander-in Chief, with his usual foresight and judgment, ordered the 2nd brigade of my division, under Brigadier Wheeler, a regiment of native cavalry, the body guard, 400 strong, and four guns horse artillery, to move from Hurrachee *viâ* Dhurmkote and Jugraon, to join me. A second brigade, under Brigadier Taylor, was ordered in support to Dhurmkote. The Shekawattee brigade was moving on Jugraon. Thus the enemy's position at Budhowal was menaced in three points: he expected considerable reinforcements *viâ* the Tulwun Ghat, eight miles lower down the Sutlej than Philour. He therefore again with judgment abandons his position of Budhowal, in which I was making vigorous preparations to attack him, and falls back upon the reinforcement of 12 guns, 4000 of regular infantry of Avitabile's corps, and a large addition of cavalry. This movement, however, must have been premeditated, from the stores of ammunition, &c., and his fortifications around. The ford was not the work of a day. I immediately occupied the enemy's position at Budhowal as rapidly as possible, concentrated my force coming from Dhurmkote and Busseean, and dispensed with the service of Brigadier Taylor's brigade in reserve at Dhurmkote, feeling myself sufficiently strong, and aware of the importance of infantry to the Commander-in-Chief, who, to reinforce me, had considerably reduced his own means in the immediate front of the main army of the Sikhs.

"This is the 'précis' of the campaign leading to the battle of Aliwal, and from this period taken up in my report of that battle. My loss during the day was of killed, wounded, and sick taken, upwards of 200 men; but many of our wounded and exhausted infantry were brought off on the artillery carriages, and by the noble exertions of H. M. 16th lancers, who dismounted and put upon their horses sick and wounded. My orders to the baggage guard, composed of irregular horse 400, and to which I subsequently added one squadron of regular native cavalry, were only imperfectly obeyed, or our loss of baggage would have been next to nothing; but young soldiers are excited under a heavy cannonade, and apprehend more of its deadly effect than I have ever seen the heaviest cannonade (not grape and canister) merit. This short but eventful campaign was one of great difficulty and embarrassment for the General (your brother). The enemy was concentrated while my force was to accumulate, contingent on a variety of combinations distant and doubtful. The end was accomplished, viz. the battle of Aliwal and its important results."

Some Account of the Passage of the Sutlej by the British Army, in February, 1846. By Captain YULE, *Bengal Engineers.*

THE native boat in use on the Upper Sutlej has a very singular and awkward appearance. It is known by the name of *chuppoo*, and is in the form of a huge, shallow, triangular tray, having the apex drawn upwards into a fantastic prow. (See Plate X. figs. 1, 2). The bottom is formed of a single layer of thick cedar planks, spiked together with irregular battens of *sissoo* wood; and the frail gunnel of thinner planks of all sorts and sizes, curiously stitched together with oblique bamboo nails. Barbarous and unwieldy as these *chuppoos* appear, they are, as ferry-boats, almost unequalled. Two or three boatmen, with long bamboo poles, guide them with surprising facility, and even laden elephants have been, during the late campaign, embarked and crossed on them with perfect safety.

Of these boats the Sikhs are in the habit of constructing bridges, after the fashion shown in fig. 3, dovetailing them together, with the heads up and down stream alternately. As the gunnels are incapable of bearing stress, a rough trestle is erected in the middle of the boat, on which are laid three or more massive balks. These, if planks in sufficient quantity are not procurable, they cover with one or two layers of fir spars, and over these spread brush-wood and earth, (fig. 4.) The alternate boats are moored by wooden anchors loaded with stones similar, apparently, to those described by Lieutenant Durand in vol. iv. page 100, of the Professional Papers. A good bridge of this kind, such as was constructed at Ferozepore in December, 1842, for the re-passage of General Pollock's army, is capable of bearing elephants, heavy cannon, or any weight that may be desired. But a very slight rise in the river is fatal to the structure.[1]

When the late Sikh invasion of the Sutlej frontier rendered a counter-invasion by the British army inevitable, nearly the whole line of the river, and all these country boats, save a very few, were in the hands of the enemy; and the Governor-General would have been unable to follow up, so rapidly as he did, his victory on the left bank of the Sutlej, by a march on Lahore, had not the foresight of his predecessor anticipated coming need.

By Lord Ellenborough's command, there had been built in Bombay dockyard a fleet of sixty boats, eleven of them armed with 12-pr. carronades, and each provided with its complement of balks and chesses for the formation of a bridge. These, under charge of Officers of the Indian navy, were towed by steamers to Kurachee, and thence tracked up the Indus and Sutlej to Ferozepore. Six boats were swamped on the voyage to Kurachee; the remaining fifty-four arrived at Ferozepore in September and October, 1845, each well mannèd by thirteen lascars. The General Government, sincere in its desire and expectation of peace, ordered the dismissal of these crews as unnecessary; and the boats, moored in a creek of the Sutlej, at Koonda Ghat (see fig. 5), were placed under charge of a company of Native Sappers.

Early in December, 1845, the Sikh army crossed by the fords and ferries above Ferozepore, and took up a position in sight of the British cantonments. The detachments in charge of the boats were withdrawn, and Lieutenant Goodwyn, of the Engineers, was ordered to sink the boats. A week afterwards, when their defeat at Ferozeshah had for a time driven the Sikhs to their own bank, the boats were raised and repaired.

In addition to the boats, there were in magazine at Ferozepore, pontoons (Pasley's) sufficient for fourteen rafts, complete with their carriages.

About the middle of January, whilst the British head-quarters were in front of the Sikh army, about 22 miles from Ferozepore, Major Abbott,[2] of the Engineers, was sent to take charge of the boats. Two companies of Sappers, and shortly afterwards two more, were placed at his disposal, and several subalterns of the corps placed under his orders, to assist him in teaching the men the management of the boats, and of the pontoons (a branch of practice which our Hindustanee Sappers had never acquired), as well as to superintend the preparation of many stores in which the boats were deficient.

Though it was not likely that more than half the boats would be required for the

[1] A slighter bridge is formed by merely packing the boats, to the breadth of roadway required, with brush-wood, and covering it with earth.

[2] Now Lieut.-Colonel Abbott, C. B.

formation of a single bridge, yet it was originally designed that the whole flotilla should be used in the first instance as ferry-boats, to throw over a body of 5000 or 6000 men, to occupy the opposite bank, and cover the construction of the bridge. Hence our calculations could allow at the utmost only a crew of one non-commissioned officer and six men to every boat; and though our Sappers learned to guide and move, with considerable exertion, these unwieldy vessels in the still-water creek to which our practice was necessarily confined, whilst the bank of the main river was occupied by the enemy, yet we could not but have serious misgivings as to the result of launching the fleet, freighted with troops, and manned by our inexperienced crews, among the shoals and eddies with which the Sutlej peculiarly abounds. Such considerations, justified by after experience, mainly led to the selection of a spot for the first passage of the river, within a few yards of the mouth of the creek in which our boats were stationed. The section was good; having a steep bank of 6 feet on both sides; under 600 feet in width, whilst the general width of the river was 1000 to 2000; and (a rare circumstance) affording depth enough for the boats throughout. But beyond the river was the former channel with a stream still flowing,—fordable, it is true, but with a doubtful bottom, and liable, by a moderate rise, to be rendered impassable (*n n*, fig. 5, Plate X.). This was the serious objection to a spot otherwise so convenient. But there was no reason to expect any lasting rise at that season, and the advantages of section and easiness of access decided in favour of this spot (G, fig. 5), for the first construction of the bridge, to be moved after the invading army should have passed, and the opposite bank should be entirely in our possession, to a site more adapted for permanent communication.

By the end of the first week in February, the Sappers had been as well trained as could be expected from practice in the still water of the creek; many defective balks, chesses, bolts, &c., had been renewed; the stores of two boats adapted to the formation of a cut in the bridge; the chain cables fitted with stoppers, and the anchors with buoys; rack lashings and dividers, which were wanting in the original equipment, had been prepared; and every boat furnished with a tow-line. The carronades of the gun-boats had been removed to Ferozepore, when the cantonment was invested by the enemy. As we had not crews capable of using the guns to any good purpose, they were suffered to remain in store, and the slides and carriages were unshipped. Railing stanchions of timber were also provided, and iron sockets for them attached to the gunnels. But these, as will be seen, were never used.

DESCRIPTION OF THE BOATS.

The boats were not all exactly alike in dimensions, though the differences were not great. They were generally $46\frac{1}{2}$ feet from stem to stern; 12 to 13 feet in the beam, and of the construction shown in figs. 1, 2, 3, 4, Plate XII. They were all furnished with excellent anchors of the pattern shown in fig. 6, and with 20 to 30 fathoms of chain cable to each. Every boat was likewise supplied with

6 oars and 2 poles.

5 balks of teak, 29′ 0″ × 9″ × 5″.[3]

Planks (teak) 12′ 0″ long × 2″[4] thick, enough for 26 running feet of roadway; cleated on the under side at 6″ from each end.

4 railing stanchions, 5″ scantling.

2 dividers, 13′ 0″ × 4½″ × 3½″.

5 iron bolts for balks, 12″ × ¾″ diameter, with keys and washers.

8 rack lashings.

2 baling buckets.

In packing stores, the planks were first laid athwart, so as to form a deck. Over these were laid the five balks longitudinally, two on each side forming a seat for the rowers; the dividers along-side the balks; railing stanchions in the hold; small stores in a sack at the stern. (See Plate XII. fig. 5.)

MODE OF FORMING THE BRIDGE.

In forming the bridge the boats were moored at central intervals of 26 feet, and the dividers fixed with the row-lock pins. The balks were then slewed round successively, and placed athwart the boat at head and stern, ready to be pushed forward as soon as another boat should be in position. The balks were very cumbrous, as their dimensions will show, and required the whole boat squad of six men to move one, which they did by the help of rope ends passed under the middle and ends. When correctly laid, the balks were bolted and keyed. This was often a work of some time, as many of the beams were warped excessively. When two or three boats ahead had their balks placed and bolted, the planks were taken up between the beams, and laid. We used the oars and poles as ribands for racking; but as most of them were crooked, they were not well adapted for the purpose. Each boat pushed forward its balks in the manner shown by the diagram (Plate XII. fig. 7), where the shaded balks belong to the shaded boats.

The plan adopted for forming a cut in the bridge at short notice, for the passage of fire-rafts, or the like, is shown in figs. 8 and 9: two boats selected for this purpose were each supplied with four balks, 29′ long × 9″ × 6″. These balks, when laid to form the raft, were pinned together over both the inner gunnels, and their outer extremities were framed together by a binder fixed across the balks by vertical pins, to give steadiness to the balks of the raft, as well as to prevent their joggling with those of the adjoining boats. (See fig. 8, where B, C are the boats of the moveable raft, A and D, the adjoining boats of the bridge.) In whatever part of the bridge it

[3] 9″ × 6″ where we were obliged to supply them of deal or cedar.

[4] This thickness was insufficient. Planks prepared at Ferozepoore were sawn to 3″.

might be thought best to introduce the cut, the balks of the boat A would be thrust back, as shown in the figure, and the short dividers *d d* placed. Short balks were also carried in the raft to supply in D the vacancies occasioned by the interruption to the interlacement of the superstructure. The planking would then be laid over the raft and adjoining boats, leaving a space of about 9″ interval on each side. Over this was to be placed a gang-board of strong planks, about 12′ × 3′, battened together (*g g*) on the under side, and levelled at its edges. Over this, at each side of the bridge, was to be laid a piece of timber (*ff*) binding down the gang-board, and strongly lashed to the balks through the racking-holes. By cutting these lashings, and unshipping the dividers and gang-boards, all quick processes, the raft would be at once cast loose.

The creek (*c c*, Plate X. fig. 5) in which the flotilla lay was crossed at its mouth by a bar rising within a few inches of the surface, and over this ran a current of back-water. A few days before the order for crossing was expected, this bar was cut through, at night, in order to avoid observation, by a party of Sappers under Lieut. A. D. Turnbull.

On the 9th February we received an intimation that we should be required to be ready to effect the passage of the river on the night of the following day. The evening before, two of our companies of Sappers had been summoned to the camp of the Commander-in-Chief, then lying before the Sikh lines at Sabraon. This considerably crippled our means, but by this time we had collected a body of one hundred and twenty *mullahs*, or river boatmen, who were likely to be useful, if not exposed to fire.

The force to be thrown across in the first instance consisted of six regiments of native infantry, and a troop of horse artillery from the divisions of Sir John Littler and Sir John Grey. For the transport of these we told off our fourteen-pontoon raft, and seven of the *chuppoos* described above, and selected twenty-eight of the best Bombay boats for the bridge.

Early on the morning of the 10th a heavy cannonade from the eastward announced that the projected attack on the Sikh lines had commenced; and before two o'clock in the afternoon the Governor-General's Military Secretary arrived in cantonments with the news of complete victory, and the order for commencing the passage immediately after dark.

The pontoon rafts were first dispatched under Lieut. Turnbull, their crews being provided with tools to restore the cut in the bar, which the morning's examination had shown to be already partially silted up from the action of the back-water. Four boatmen were then told off to each *chuppoo*, and the remaining boatmen and sappers equally distributed among the bridge boats. The distribution therefore was nearly as follows:

	Native O. and N. C. O.	Sappers.	Boatmen.
Fourteen pontoon rafts	14	84	—
Seven chuppoos	—	—	28
Twenty-eight boats	28	98	98
Total	42	182	126

By the time these distributions were completed, it was judged that the work at the bar must have been executed, and the fleet was started quietly, the chuppoos (with a guard of infantry) leading, and the bridge boats in rear. By $8\frac{1}{2}$ P.M. Sir John Grey's three regiments had arrived from their camp at Ataree (see fig. 5, Plate X.), and were halted at some distance in rear of the bank. The troop of artillery was placed so as to cover the passage, and as soon as the pontoon rafts had passed the bar, the infantry were moved up and embarked in squads of from twenty to thirty men on a raft. There was no symptom of opposition to the passage. When the chuppoos arrived, the process of crossing became more rapid, as these were capable of carrying a company at each trip. Though we had the advantage of a fine moon, delays occurred from the pontoons grounding occasionally, as the space affording a clear section was very limited, and the current was considerable (about $2\frac{1}{2}$ miles an hour). The artillery were crossed in chuppoos, a gun and limber, or waggon and limber, with six or seven horses, at each trip. This was rendered very tedious by the vice of the artillery horses, contrasting remarkably with those of the irregular cavalry which passed afterwards. The latter packed close, thirteen to sixteen in a boat, without any difficulty. After Sir John Grey's infantry had passed, there was some delay in the arrival of the remainder of the force, but early on the forenoon of the 11th, the whole had been thrown over, and occupied the Sikh bank, viz.:

6 regiments of native infantry.
1 troop of horse artillery.
5 troops, irregular cavalry.

About sunrise a considerable body of the enemy's horse showed themselves along the high bank of the channel *n n* (Plate X. fig. 5), but on a movement being made towards them, they dispersed, and were seen no more. It had been resolved, early in the night, when it became evident that no opposition was to be looked for, that the formation of the bridge should be deferred till morning. From the difficulty still of passing the large boats over the bar, it was 10 A.M. before the actual bridge operation was commenced. This was done by mooring a pontoon raft with a large anchor near the middle of the stream. From the near bank a sheer line was passed to the raft, and along this line the boats were warped successively till they came opposite their proper positions. They then let go, cast their anchors in the proper alignment, and dropped with the stream into position. When the middle of the river was passed, a second line was carried up-stream, and fixed to the other bank. On this the remaining boats, having passed from stern to stern of those already placed, warped opposite their positions as before. Where the anchorage happened to be in shoal water, the anchors were carried out and cast from a chuppoo.

At 7 P. M. of the 11th all the boats were in position, save four, and the greater portion of the roadway had been completed. The two companies of Sappers had worked in a most praiseworthy manner (with an interval of only three hours' rest), for thirty-six hours, without relief. By this time, however, the other two companies had rejoined from the field of battle, though they were not capable of recommencing work till next morning.

12th.—At 3 A. M. the work was renewed, and by 9½ A. M. the whole of the roadway having been laid with tamarisk brush-wood, and a considerable portion of it with earth also, the bridge was opened for the passage of the guns and cavalry of Sir Harry Smith's division, the greater part of his infantry having been ferried over already. The Commander-in-Chief arrived also, and crossed that afternoon. During the intervals between the passage of troops, the pressure of camels, carts, ponies, doolies, camp followers, and even elephants (the passage of which by the bridge was absolutely prohibited), towards the head of the bridge, was beyond all conception of those who have not seen the *impedimenta* of an Indian army. Nothing but the whip of a stalwart Provost Martial, and the volunteer assistance afforded him, from the highest to the lowest rank in the army, availed to keep our bridge from utter annihilation. This pressure continued with scarcely any visible diminution for four days.

It was not thought advisable in the formation of this bridge to cast the stern anchors; and consequently the great weight of the stream cables rendered it impossible to haul them sufficiently taut. Many of the balks also were warped excessively; so that the dressing of the boats shifted, and was never perfect. Hence the roadway could not be accurately adjusted to the sockets prepared for the railing stanchions, and the railing was not constructed; nor was it required. No serious hurt occurred to man or beast during the passage of the army. If an awkward camel did get his leg over the side, and lie in helpless imbecility, as is the manner of camels in difficulties, without an effort to extricate himself, the load was at once canted into the nearest boat, and the animal pitched overboard; but not one lost its life.

It was judged unnecessary to complicate the construction of the bridge by the introduction of the cut above described, as there was now no probability of its being required.

This afternoon, observation of the rate of passage of the miscellaneous baggage train gave 64 in five minutes for the number of camels, ponies, doolies, &c., which crossed.

The bridge consisted of 21 boats.

13th.—This morning a second bridge was commenced, about 70 yards below the first. A detachment of eight 24-pounders passed over. The elephants were unyoked, and the guns drawn over by the Sappers, without the slightest accident, and with very little perceptible depression of the boats.

14th.—By sunrise the new bridge was completed, and was of great use in dividing the pressure of baggage.

18th.—The remainder of the heavy artillery crossed.

19th.—By this time nearly the whole of the baggage of the army had crossed. Nuggur Ghat, about nine miles further up the river, had been fixed on as a site for the reconstruction of the bridges, as being free from the objections to that originally used. The upper bridge was broken up, and with all the spare boats dispatched to Nuggur.

20th, P. M.—The bridge at Nuggur was commenced. As the width here was 700 feet, and required 27 boats to span it, whilst the breadth of clear section was insufficient for two bridges, it was resolved to have but one bridge with a double roadway. Danger had occurred in the first bridges from the balks working from their places on the gunnel, and so rendering the bearings of the planks too great in many places. To avoid this in the new bridge, cleats of deal scantling were fixed on every gunnel after the balks had been placed, so as to allow only an inch or two of play either way. (See fig. 1, Plate XI.) The left bank at Nuggur was high and bold, but the right was a low shelf of sand, so that it became necessary to construct a long causeway and an artificial pier head. This is shown in fig. 1, Plate XI. The short balks of the land bay rested on a large timber, fixed as shown in the section, fig. 2; and their other ends were bolted to the bridge balks, just over the gunnel of the first boat, so as to form a hinge allowing of the easy rise and fall of the platform. In this bridge the whole of the stern anchors were cast, which enabled us to effect a very perfect dressing, and the boats were lashed together head and stern with the span of the chain, so as to take some strain off the dividers. The single roadway was opened on the 25th, and the same day the remaining bridge below was broken up and dispatched to Nuggur. On the 1st March, the second platform was completed, and as there was at this time little traffic, we were enabled to form an excellent road on both lines by a thick substratum of tamarisk brush-wood, well covered with stable litter and earth, mixed and trodden.

A bridge head, with flanking batteries on the near bank, had been originally designed. There was no longer any likelihood of such a work being required, but the lunette was constructed at the same time with the bridge at Nuggur, partly as a useful practice for the Sappers, and partly as a necessary defence against the enemy whom we had now most reason to dread, the baggage of our own returning army. And in this way the field-work did prove eminently serviceable.[5]

8th March.—A slight rise in the river having given the current a bearing towards the

[5] The writer having been at this time ordered to rejoin his ordinary duties, he is indebted for the remaining particulars to Lieutenant Turnbull, who remained in charge.

pier head on the right bank, the piles were getting rapidly undermined. It was hoped that an oblique spur of 12-foot piles, driven a short distance above the bridge, would prove an effectual protection; but before long, this also was seriously breached. Next day, sand and brush-wood in layers were heaped behind the spur, so as to form a solid mound from the shore to the nearest boat. This was quite successful, but gave rise to unlooked-for difficulties when the anchors came to be heaved.

On the 9th also, thirty-two Sikh guns crossed: one of them, a huge 32-pounder, having all its weight thrown on two wheels, broke a couple of balks in passing. These were replaced in two hours.

On the 26th March, His Excellency Sir Hugh Gough re-crossed the Sutlej, accompanied by the 3rd dragoons, the 3rd, 4th, and 9th native cavalry, Christie's and Tait's irregulars, Grant's, Alexander's, Brinde's, Lane's, Campbell's and Jacbett's troops of horse artillery, H. M. 9th, 10th, 29th, 53rd, and 62nd foot, the 1st Bengal Europeans, the 16th (native) grenadiers, and the 26th and 73rd native infantry. The whole of these and their baggage crossed without accident, and by 3 P M. the bridge was clear; though in the early part of the day the crush outside the field-work was tremendous; the ditches were choked with camels, ponies, &c., and even the exterior slope covered with a living revetment, but the inside of the work was kept clear and orderly.

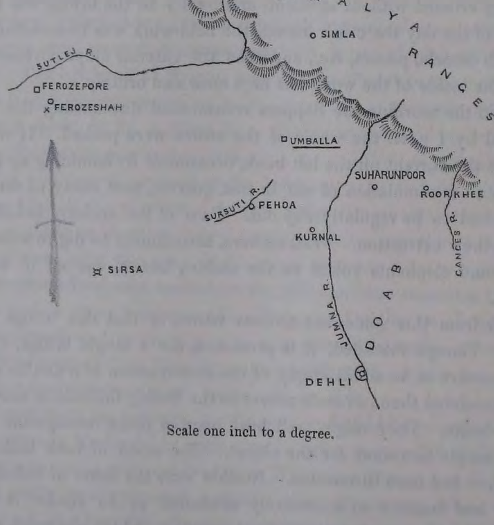
27th.—Early in the morning the Sappers commenced dismantling the two roadways successively, and by 1 P. M. the whole of the stores were packed. It was now found that the check to the current on the left bank, occasioned by damming up the shore bay, had caused such an accumulation of silt in that quarter, that many of the anchors and one of the boats had to be regularly *dug* out. Four of the anchors defied all available contrivances for their extraction. Well-sinkers, accustomed to dig in water, were set to work at them, and elephants yoked to the tackle; but it was all in vain, and they were abandoned.

It will appear from this somewhat tedious narrative that this bridge equipage had several defects. Though intended, it is presumed, for a single bridge, the size of the boats was so excessive as to admit amply of the construction of a double roadway; and this great bulk rendered them, in such a river as the Sutlej, difficult to move, and nearly useless as ferry-boats. They might well have been of more manageable size, and yet have possessed ample buoyancy for the object. The wood of both balks and chesses was ill-seasoned, or had been ill-selected. Neither were the latter of sufficient thickness, and the former had become so excessively contorted as to render it impossible to provide beforehand a system of cleats for their reception, which was much required.

Altogether the flotilla was not a handy one for forcing a passage against resolute opposition.

Although not exactly à propos of the passage of the Sutlej, I wish to put on record, as an interesting fact connected with the late campaign, the distance to which the cannonade at Ferozeshah on the 21st and 22nd December, 1845, was audible, as being, I believe, altogether unprecedented. It was heard by the writer and many other officers then marching to join the army at Pehoa, distant from the field 115 miles S. E. It was heard at Simla, 30 miles within the Himalya Range, and 134 miles E. by N. from the field; at Sirsa, 88 miles S. by E. from the field; at Kurnal, 150 miles S. E.; at Umballa cantonment, 119 miles E. by S. These instances rest on European testimony. But finally there is good native evidence of the fire during the night of the 21st having been heard at Roorkhee, the head-quarters of the Ganges Canal establishment, distant 189 miles E. S. E. from the field. These places are shown to scale in the following sketch.

H. YULE,
Captain, Bengal Engineers.



Scale one inch to a degree.

Fig. 5.

Sketch *to illustrate* THE PASSAGE OF THE SUTLEJ, *by the* BRITISH ARMY. 10th 11th February, 1846.

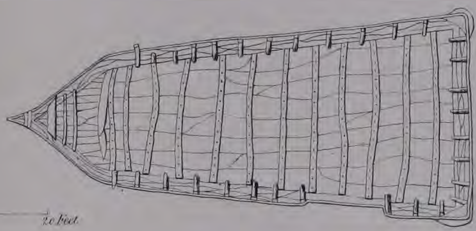
John Weale, 59, Hig

PLATE 10.

Fig. 1.

Plan

Fig. 2.



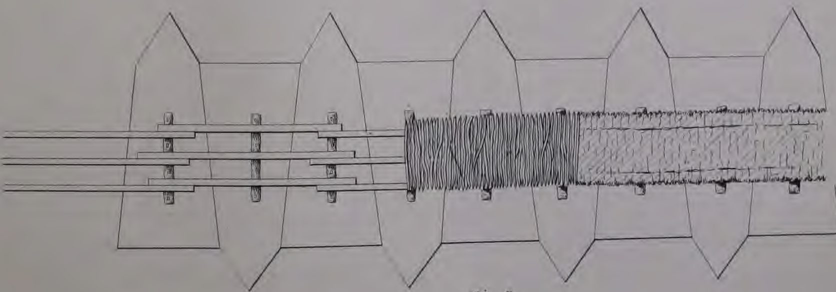
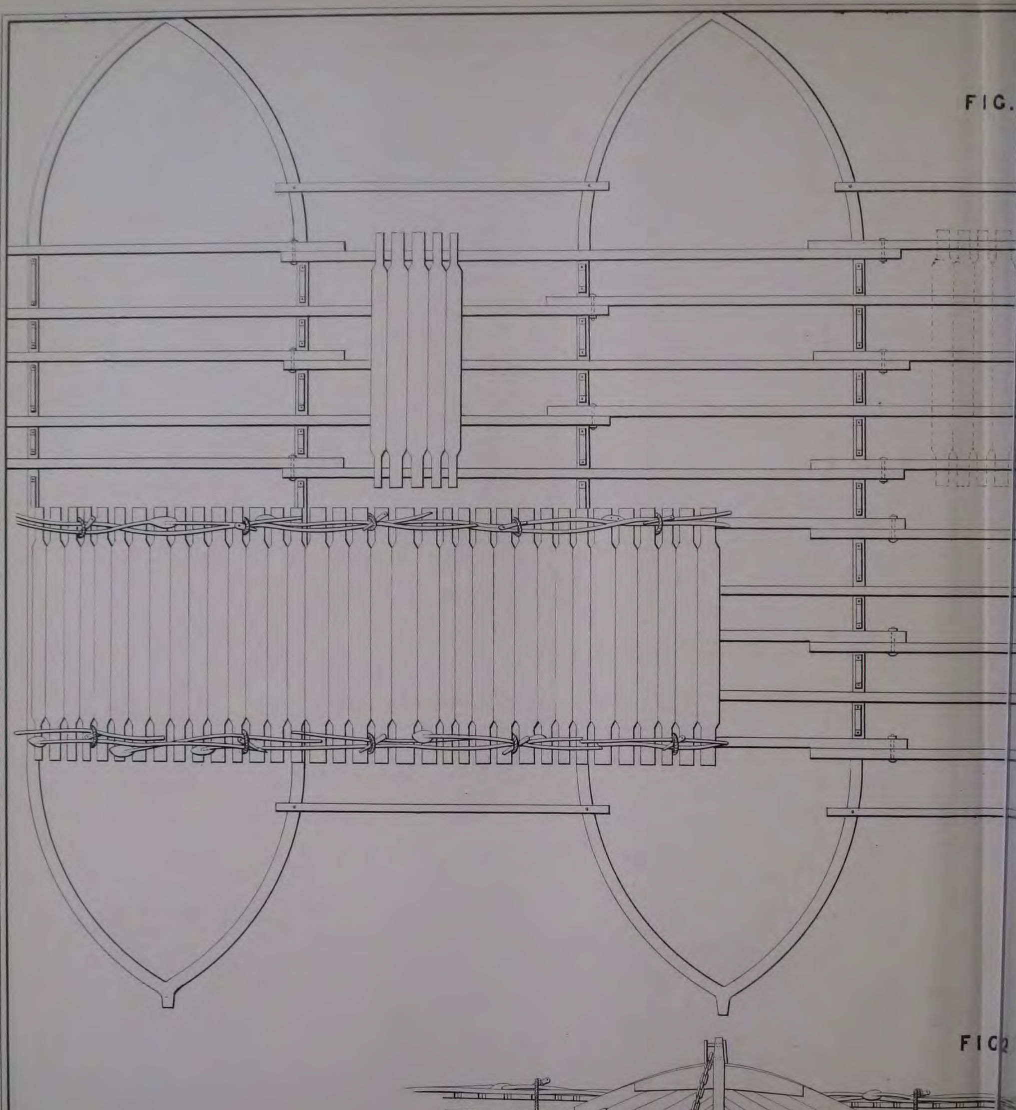


Fig. 3.

Fig. 4.

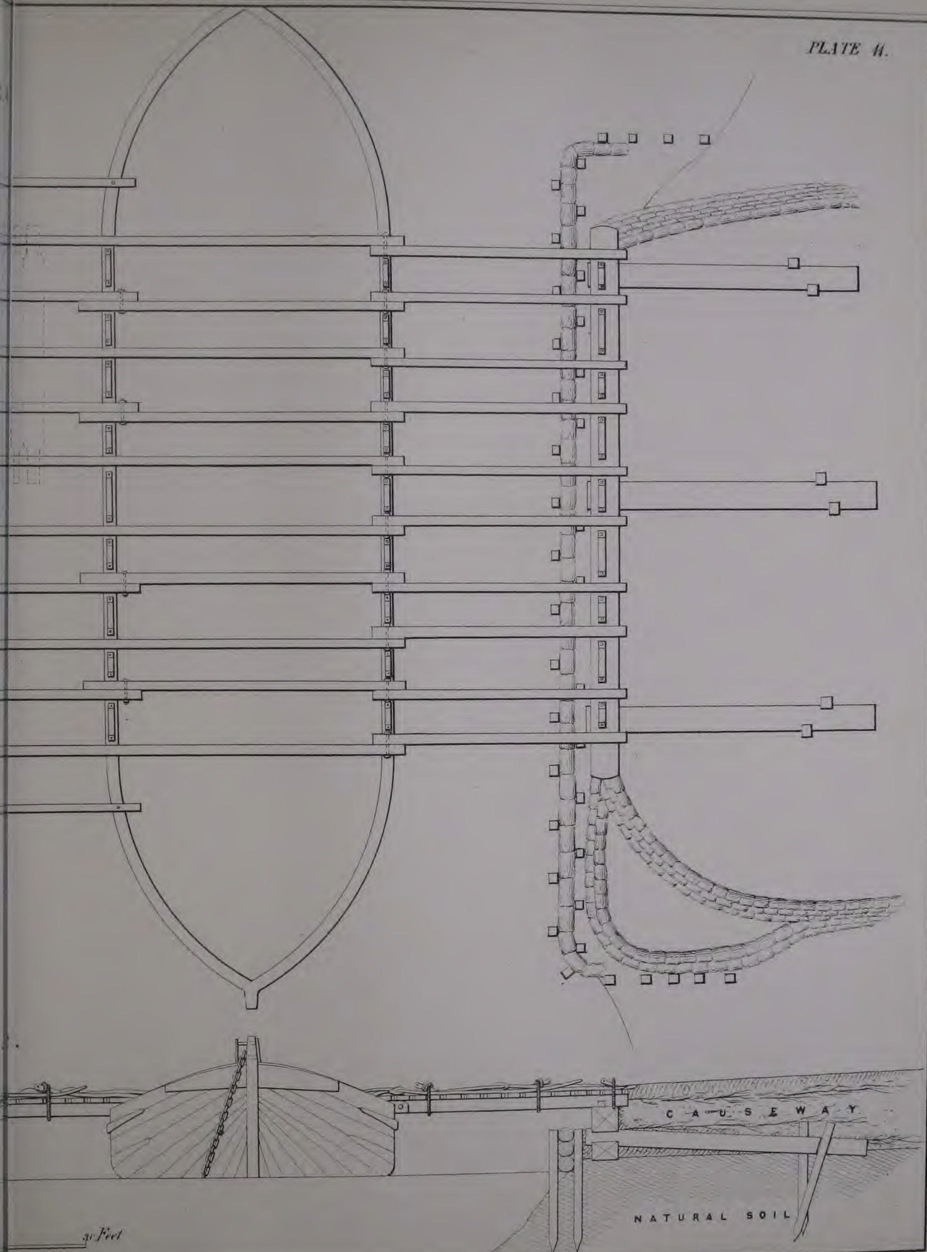
C.F. Cheffins, Lithog^r Southampton Build^s Holborn.

born, 1849.



John Weale, 59, High

PLATE 41.



C.F. Cheffins, Lithog. Southampton Buildings.

born. 1849.

FIG. 1.

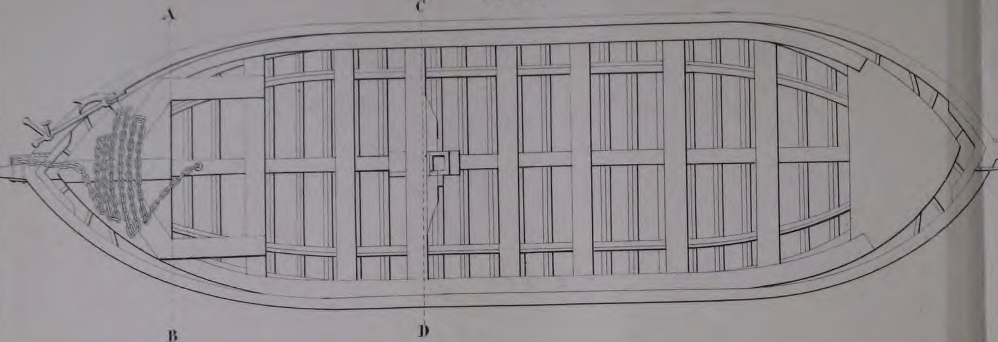


FIG. 2.

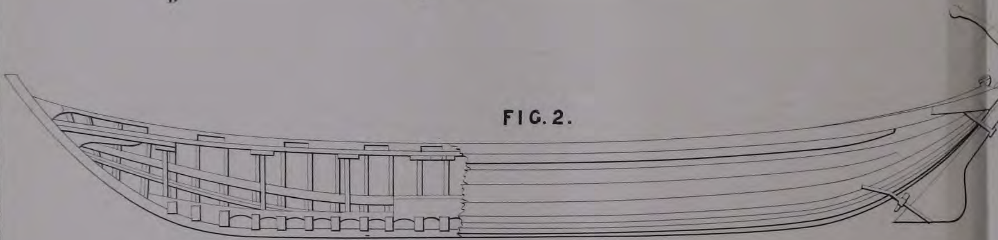


FIG. 3.

SECTION ON C D WITH STORES PACKED.

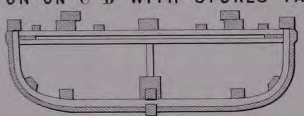


FIG. 4.

SECTION ON A B.

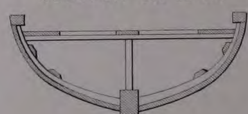
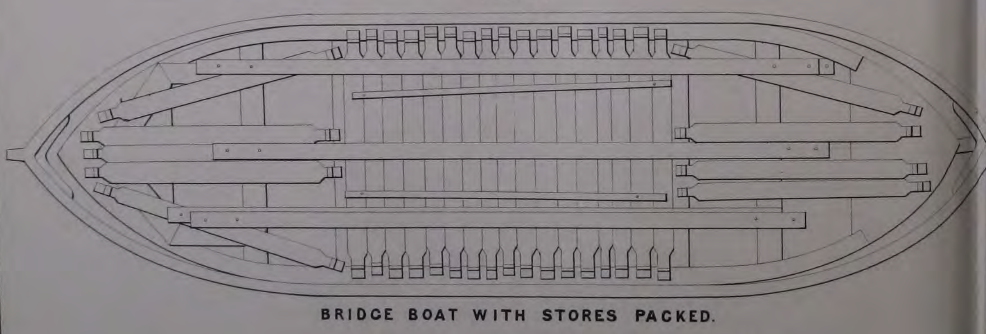


FIG. 5.



BRIDGE BOAT WITH STORES PACKED.

SCALE TO FIGS. 1. 2. 3. 4. 5. OF THIS PLATE.

Feet 10 5 0 10 20 30

John Weale, 59, High Holborn, 1849.

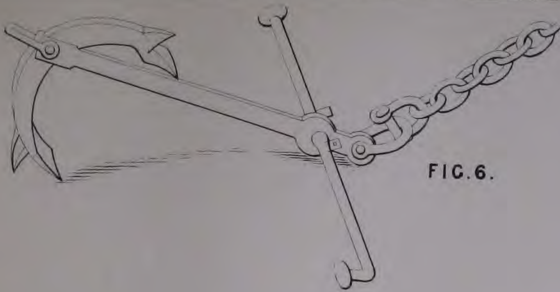
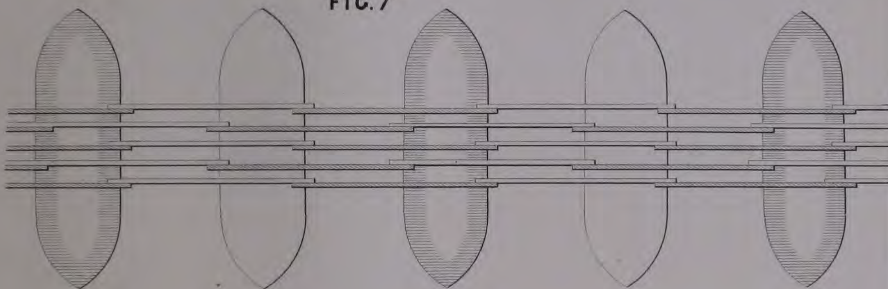


FIG. 6.

FIG. 7



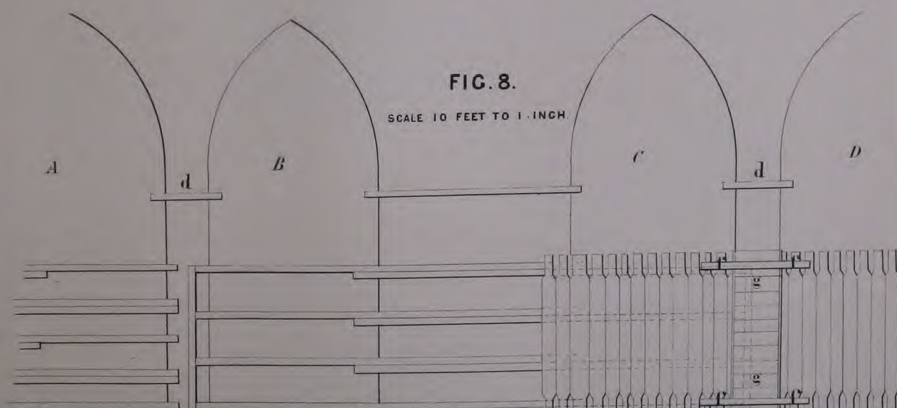
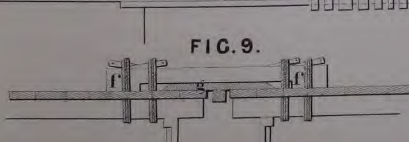


FIG. 8.

SCALE 10 FEET TO 1. INCH.

FIG. 9.



10 Feet

C. F. CHEFFINS LITHOG. LONDON.

VIII.—*Mode of Closing Windows at Pisa.* *By Lieut.-Col.* P. YULE, *R. E.*

THE mode of closing windows, as described in the following figures, is used at Pisa. I do not know if it be peculiar to that city.

It is well adapted for public buildings, being cheap, and not liable to get out of order.

In the scale of expense, as compared with the 'spagnoletta,' which is in ordinary use in Malta, it is less than one-half; it will cost here 3*s.* 7*d.*; the price of the spagnoletta is about 7*s.* 6*d.*

ESTIMATE.

	s.	*d.*
Eight running feet, $1\frac{3}{4}$ inch square wooden bar to secure the sash .	1	4
Three hinges, $2\frac{1}{2}$-inch, with screws for do.	1	0
Two iron $\frac{1}{4}$-inch hasps, with screws for do.	0	9
Two turn-buttons for the shutters	0	6
	3	7

P. YULE,
Lieut.-Colonel, Royal Engineers.

Malta, 1845.

Section on *a b*.

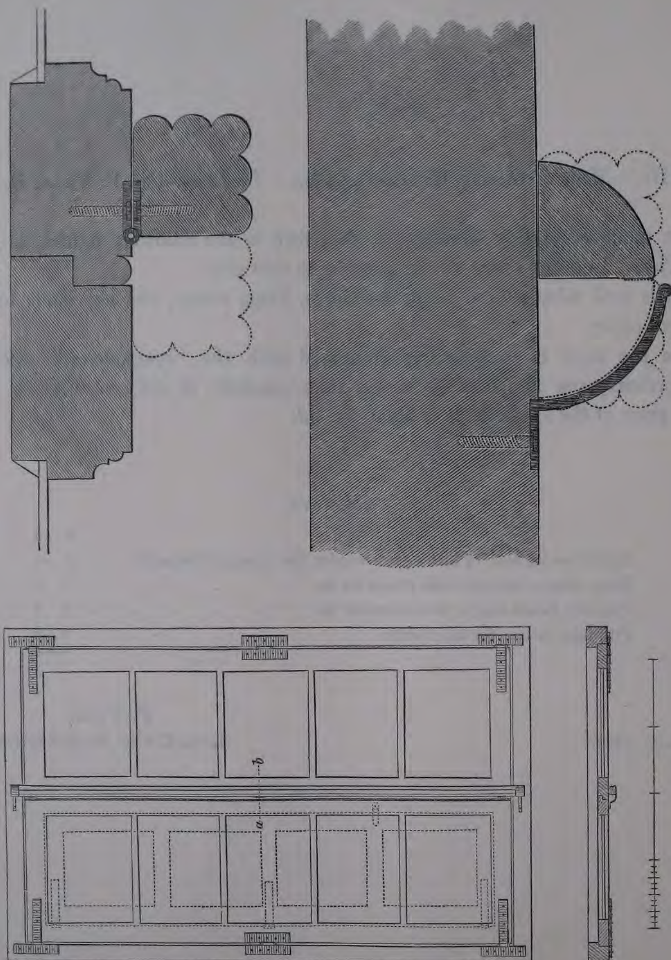


Plate 14.

James Noble Archt. delin.

J. W. Lowry fecit.

WRECK OF THE BRIGHTON CHAIN PIER AS SEEN OCT^R. 16^TH 1833.

John Weale Architectural Library, 59 High Holborn. 1849.

IX.—*A Resultant System for the Construction of Iron Tension Bridges.* *By Major* HENRY GOODWYN, *Bengal Engineers.*

THE view of the wreck of the Brighton chain pier, as here exhibited (see Plate XIV.), is a fac-simile copy of Plate 90 of the 'Theory, Practice, and Architecture of Bridges,' published by Mr. Weale in 1843, in which the following brief yet speaking account is given: The span of each curve is only 255 feet, with a deflection of $\frac{1}{14}$th. The damage to the structure occurred in October, 1833, when two curves and their platforms were destroyed. The second from the land side had twenty suspending rods carried completely away, and many others seriously injured; the third division had fifty-eight suspending rods destroyed. The chains were greatly deranged, and three-fourths of the platform and railing completely destroyed; the two divisions presenting an awful ruin. A rapid undulation was produced in the platform during the storm, and it sank nearly 6 feet on one side, presenting an inclined plane transversely.

It is remarkable, that notwithstanding the violent injury which the storm produced, the longitudinal iron bearing bar, with a sectional area of only 4 square inches, was not broken, though it suffered severe torsion. A bar of the above section supported the girders of the roadway to which the planks were fastened, and which bars were upheld by the stirrups at the lower ends of the suspending rods.

These remarks are made with reference to paragraphs 3, 4, 5, and 6 of the following Memoir, and Plate XIV. is introduced as an evidence of there being some great defect in the principle of construction which admits of a structure, pronounced as one of Sir Samuel Brown's best works, being so seriously deranged by merely its own weight, thus acted on.

The following practical conclusions are chiefly drawn from the demonstrated results of a 'Memoir on the Quantity of Iron necessary in a Tension Chain

Bridge,' by the Rev. J. H. Pratt, published in the 'Journal of the Asiatic Society' in Calcutta, No. CLXXXVI., for January, 1848;[1] and although a modified taper chain system had been drawn out and partially put into practice by me before the appearance of Mr. Pratt's theory, its principles agree so entirely with my own experience, and its demonstration is so clear, that I have been induced, from the wish to promote the advancement of such structures, to place the following exposition of my system on record, feeling sure that unbiassed minds will, on perusal, be divested of the timidity with which the extreme or Dredge's taper chain system has been received, as its errors have been admitted and corrected; whilst, if there be any virtue in the present uniform chain system, the proposed 'Resultant' will be found to possess them in an eminent degree, and yet freed from its acknowledged defects.

1. The fact demonstrated in the above-named Memoir is simply this, that in all iron suspension bridges of equal span, and breadth of platform, the quantity of iron in the main parts must be *the same*, and that quantity which "is necessary to enable each part to sustain the greatest tension to which it may be subjected when the roadway is loaded to the greatest extent, is *altogether independent* of the principle of construction or form of the bridge," provided, of course, that the principle be sound.

2. This is a very important conclusion; but whilst I freely admit the soundness of the doctrine, I am not fully satisfied as to the correctness of the writer's practical deductions therefrom, viz. that the old system of suspension, consisting of a uniform chain and vertical drop bars, is the most proper for adoption under all circumstances.[2] For such an opinion the author of the Memoir gives his reasons, which, as might have been expected, are weighty enough;—but "*good* reasons must perforce give way to better;" and notwithstanding what has been advanced above, I think the scale may yet be turned in favour of the opposite opinion, viz. that the old or uniform chain system is by no means necessarily, and under all circumstances, the most desirable for adoption.

3. If the strength or stability of a structure to resist a constant dead weight were alone the points for consideration, the advantages adduced in favour of

[1] See Appendix, page 221.

[2] This does not appear to be Mr. Pratt's conclusion, which was, that as it is difficult in practice to adjust the strength of the iron to the tension of each part in a complicated structure, the uniform had the advantage over the taper system.—*Editors.*

the uniform chain system might be conclusive; but wherever failures of suspension bridges have occurred, they have in almost every case been caused, *not* by a steady, uniform dead strain, exceeding the power of the materials to resist, but by the effect of a much smaller load or weight in a state of a motion—*not*, for instance, during a trial by means of a *proof load* uniformly distributed, but by the *motion* of a far smaller weight, as of a company of soldiers marching in step, as occurred to the Broughton bridge, near Manchester; nay, the great Menai bridge, which was calculated to be equal to a load of 1245 tons in excess of its own weight, and the Brighton chain pier (see Plate XIV. and description thereof) to an extra load of 100 tons, have both been nearly destroyed by merely their own weight, when put in motion by a violent wind. The large suspension bridge at Montrose was destroyed in a similar manner, which, when first put up, was proved by a dead weight of 970 tons, being the greatest it would have to bear.

4. The disastrous effects which have already occurred, and may still be apprehended from such causes, to bridges on the uniform chain system, are so universally admitted, that they need not here be further dwelt on. It will suffice to notice that no bridge of large span, in any exposed locality, is ever put up without some special arrangement to counteract the vibratory and undulatory tendencies of the structure: this protection is sometimes attempted by means of guy chains, sometimes by a system of side and under trussing (as in the Hammersmith bridge), at others by counter-chains (as in the Brighton pier), the latter being intended to enable the platform to resist the lifting power of the wind from below.

5. From the result of the opinions on the disastrous effects of gales on the Menai bridge in the years 1826, 1836, and 1839, and especially when, during the latter, 148 or one-third nearly of the suspending rods were torn asunder, no other conclusion can be drawn, than that the tubular rods introduced between the chains, the trussing of the roadway, the small brace chains, &c., did not preserve the bridge from the effects of the combined motions of the vibration and undulation of the chains,[3] which was the primary cause of the injuries sustained; and the reason is evident, viz. that these accessories contended against the *effect*, without attacking the *cause*. It will be therefore evident that something more than strength to resist a known strain in a

[3] *Vide* 'Report by Mr. Provis, Resident Engineer,'—'Trans. Inst. Civil Engineers,' vol. iii. page 357.

certain direction is required; and however true the main position demonstrated by the Rev. Mr. Pratt may be, it still remains an open question whether, in order effectually to meet the varied strains and trials to which suspension bridges are peculiarly liable, some other arrangement of the *same quantity of metal*, as is now given to bridges on the uniform chain system, may not with advantage be employed.

6. Here it will not be irrelevant to observe that all the expedients had recourse to, for the purpose of counteracting the vibration and undulation of the uniform chain bridges, not only, of course, increase the expense and weight of the structure, but absolutely negative the principal advantage expected from, and claimed for, that system, (viz. the simplicity and directness of the strains,) in the ratio of their attaining the object for which they were added, *i. e.* the stiffness of the whole.

7. Before proceeding to show, and I trust to prove, what will be a more advantageous disposition of a given weight of metal in a bridge of known size and proportions, than that which would be attained by the uniform chain principle, it will be necessary to notice a mode of construction for which a patent has been obtained by Mr. Dredge, who proposes to erect bridges of equal, or even greater strength, than those on the uniform principle, with about one-third of the quantity of iron usually employed in the latter: but as the practicability of such a result is wholly at variance with the demonstration proved by the calculations of the Rev. Mr. Pratt, now under reference, —and as no one has yet impugned the correctness of the formulæ on which the strength of the uniform chain system is calculated,—it is scarcely necessary to do more than base the rejection of Mr. Dredge's extreme taper chain system on the grounds of its non-conformity with the rules quoted above: unfortunately, however, the Ballee Khâl bridge, near Calcutta, originally constructed in strict accordance with this principle, which fell by its own weight, and the inability of the Kubudduk bridge, near Jessore, in Bengal, to withstand the ordinary proof trial, together with its subsequent failure, sufficiently confirm the accuracy of Mr. Pratt's conclusions. The latter bridge was constructed by Mr. Dredge himself.

8. In the beginning of this Memoir I remarked that I had practically, *i. e.* experimentally, corroborated the fact demonstrated in Mr. Pratt's Memoir;[4]

[4] *Vide* account of experiments at the end of this Memoir.

and the failure of the Ballee Khâl bridge led to so much study and research into the principles which should govern a taper chain bridge, that the result has been an encouragement to combine the taper chain with the uniform system, possessing in conjunction the advantages of each, with the positive defects of neither; and which I will presently explain, after glancing at the evils which are acknowledged to exist in both the above principles.

9. The most important fact gleaned from the above experience and research is one entirely overlooked by Mr. Dredge, viz. that where *strength* or *section of iron* is taken away from the chains, it should be made good in the *longitudinal beams* to which they are connected,—not that the precise quantity abstracted from the former should be added to the latter, but that additional strength should be given to the beams, bearing a certain ratio to that taken from the chain. Mr. Dredge's and the uniform chain system afford instances of opposite extreme cases. In the former, the section of the outer longitudinal beams at the centre, where the chains are a minimum, should be nearly equal to the entire section of the chains at the point of suspension, the portion of beam in the centre of the bridge standing in place of the chain theoretically, and almost so *in practice:* in fact, the longitudinal beam is an indispensable item in the Dredgeian combination, whereas in the uniform system the reverse is the case; for by the non-diminution of the chain in the centre, there is no absolute necessity for the longitudinal beam as a component portion of construction.

10. The principal defects of Mr. Dredge's extreme taper system are,—

1st. The hazard of trusting a bridge, whatever the span may be, to the strength of *one* or even *two* rods at the centre; for admitting, for the sake of argument, that the section there may not be disproportioned to the strain, yet the fracture of the link in the centre (and being so slender there, is the greater probability of such an event there than elsewhere) would be attended with very dangerous results: the conclusion therefore to be drawn from the admitted inexpediency of confiding in the strength of so small a section of iron in the very centre of the bridge is, that the chain should not diminish so rapidly as in the extreme taper system it does.

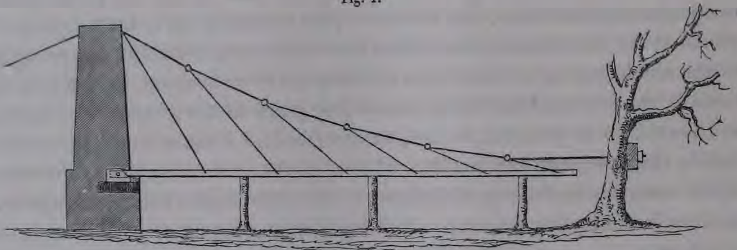
11. 2ndly. As noticed above, the section of iron in the longitudinal beams is uniformly weak throughout with reference to the tension at the centre, which, where the beam comes in place of the chain, is infinitely great, as compared with that exerted near the standards.

12. Here, as regards the second defect, it may be objected, that Mr. Dredge never intended his bridges to be sustained by tension in the longitudinal beams at any point of their length, assuming his theory that "the tension at the centre is a cypher;" the capacity of the platform to resist *compression* in the two half-curves, and not the power against *tension*, being brought into action.

13. Such has been Mr. Dredge's view, and his rule of construction; but experience on a full-sized scale (independent of the failure of the bridges above noticed) has satisfied me that there is not strength in the combination of the platform to resist compressive power. The defect was proved as follows:

14. The whole of the iron-work of a complete half-curve of a bridge of 120 feet span, and 16 feet width of platform, was put up in the Government iron bridge-yard on standards erected of masonry for the purpose, thus:

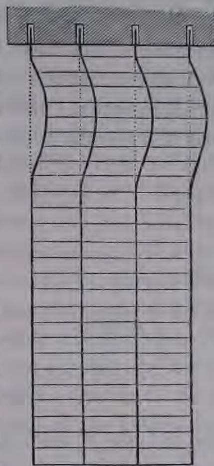
Fig. 1.



The centre link was carried out horizontally in its proper position, and attached to a wooden beam abutting against two trees. The central ends of the longitudinal beams were left free, as shown above; the other ends being built firmly into the masonry in their cast iron boxes, whilst the half-platform rested on three posts on each side, to preserve the horizontality till the whole was put up. Every thing being in position, the transverse beams, railing, &c., fixed, it is evident that on the removal of the posts the structure would not fail, if there was sufficient stiffness in the combination of the framing to resist the compressive action by the combined oblique pull of the auxiliary rods depending from the chain: accordingly the posts were, one by one, removed, when it was immediately seen that there was not that degree of stiffness in the framing to resist the amount of compression from the centre towards the standards; for when all the posts were removed, about one-third of the length of the platform from the standards was bowed out 25 inches, as in the annexed figure.

There was at this time no extra load on the platform, and the conclusion seems obvious, that unless the longitudinal beams be kept straight by tension from the opposite half-curve, the groining could hardly bear its own weight, far less be equal to a traffic load of 112lbs. per square foot. In other words, the combination and scantling assigned by Mr. Dredge has not strength to resist compression; the stability therefore of the structure must depend on the capability of the longitudinal beams to resist tension.

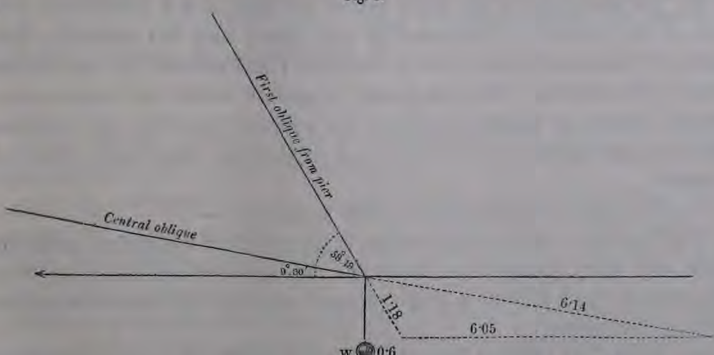
Fig. 2.



Mr. Dredge has, in fact, carried the principle too far, and has concluded that, because the lowest point of a chain is that of least tension, such an arrangement may be effected by which there shall be none at all. He has also assumed perfect rigidity for his platform, which is composed of a flexible combination, and which, if in the slightest degree displaced, causes collapsion of the whole.

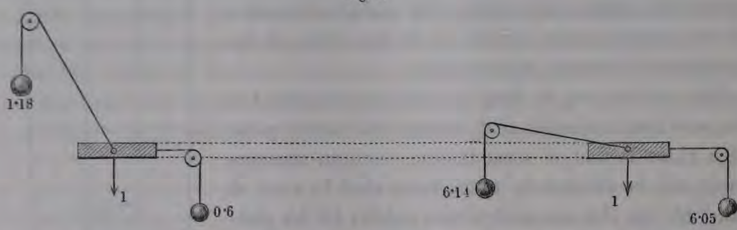
15. The third defect in the extreme taper chain system is the great obliquity of the central auxiliaries, and the great difference in the angles of obliquity,

Fig. 3.



varying from 10° at the centre to about 65° at the standards: the strains to which they are exposed by equal weights are consequently very unequal. This conclusion hardly requires elucidation; but the subjoined diagram, fig. 3, drawn to a scale, and on the principle that when three forces are in equilibrio the strains in each direction are proportional to the sides of a triangle in the direction of the forces, shows the actual tension on the central oblique rod, and in that nearest the standard, of a bridge constructed strictly on Mr. Dredge's system; the angles of attachment being 59° 19′ at the standards, and 9° 30′ at the centre.

Fig. 4.



Or, as in fig. 4, the weight being in both cases expressed by unity, the tension on the first oblique rod from the pier will be 1·18, and the horizontal tension 0·6, whilst that on the central oblique rod will be 6·14, and on the horizontal line 6·05; so that equal sections of iron are strained in the proportion of 6 to 1.

16. The advantages of the above system are, first, that a considerable portion of the platform is supported by rods direct from the standards, thus leaving a diminished tension due to the chain; and secondly, by the oblique action of the auxiliary rods the system is retained under the dominion of a certain amount of tension, rendering the roadway free from the injurious effects of undulation and vibration, and making the transit more firm and pleasant.

17. The defects of the uniform chain system are,—

1st. The whole weight of the bridge is supported by the chains, rendering them very heavy, massive, and costly, as also more susceptible of receiving the impulse which in storms is the primary cause of the destructive motion given to the roadway.

18. 2ndly. The platform being wholly supported by the action of gravity, the equilibrium of the system is disturbed by the most trivial causes: the transit even of a single foot passenger over a bridge of 200 feet span produces a sensible vibration, whilst the motion of heavy bodies is attended by effects

actually injurious to the structure; and it may therefore be readily conceded, that the effect of storms is very much to be dreaded, of which the Menai bridge, the Brighton pier, and the Montrose bridge, are instances.

19. Few, if any, suspension bridges on the uniform system are constructed on any very close calculations of the strength of the different parts; generally a very wide margin is allowed over and above the power required by calculation: thus the Menai bridge is equal to a permanent load of nearly 400 tons above the weight of suspended roadway, added to a full load of 75 lbs. per square foot; and the bridge at Montrose is equal to nearly 100 tons in excess of the entire load to which it can be subjected; yet notwithstanding this excess of strength in actual section of iron in the chains, these bridges have been in imminent danger of total destruction, when *unloaded*, from what may safely be called the defects of construction. Surely nothing need be added to show the inexpediency of providing a vast excess of strength in any structure to meet a dead weight which it can never be subjected to, and at the same time leave it unprotected to encounter the danger of disruption to which at any hour it may be exposed from natural causes.

The lately constructed bridge at Hungerford Market over the Thames, 676 feet span, has a sectional area of 312 square inches; and as the actual tension on the chains, even with the enormous assumed weight of 170lbs. per square foot of the platform, could not exceed 1420 tons, which, at 9 tons per square inch, requires 156 square inches, there is exactly double the section or strength necessary for the structure.

RESULTANT SYSTEM.

20. I will now proceed to explain a system which only proposes to do what the formulæ in Mr. Pratt's Memoir say may be done,—which is based on the experience and research I have above noticed, and which proves what it engages to do in a manner, I trust, unexceptionable; for already have the Ballee Khâl bridge, the Kubudduk bridge, and five other bridges, of spans varying from 200 to 120 feet, which were originally constructed on the extreme taper chain principle, been (as far as was practicable) remodelled on the system I am about to advert to, and most of which have now been erected three years, fully proved by previous loading, and subjected to very heavy traffic and storms. It is merely a different application of the uniform chain system, though it partakes of both that and the taper chain. I term it 'The Resultant,' indicating

thereby that the chains by construction are, in absolute strength and in the direction of their links, "resultants" of the tensions due to the adjoining link and auxiliary depending therefrom. It is, in fact, emphatically a system of equilibrium: the chief differences between it and the old system consist in a modified reduction of the section of iron in the chains from standard to centre, with a corresponding increase in the horizontal power in the opposite direction, —in fact, transferring the horizontal tension, which, together with the oblique, is borne by the chain in the uniform system, to the line of the platform by means of the deviation of the suspending rods from the perpendicular.

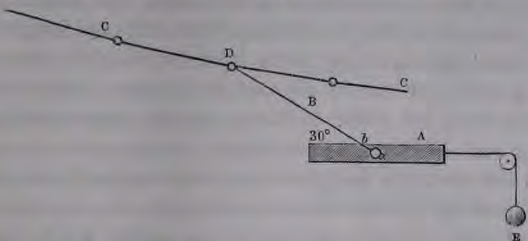
21. In the uniform chain system, as is well known, the suspending rods are vertical; in the "resultant" they are set at an angle with the roadway; and in proportion to the deviation of this angle from the vertical line, a new element is brought into operation, viz. tension in the horizontal line. This does not affect the principle of construction, but only renders necessary a new distribution of the forces required to support the structure: this will be evident from the consideration of the annexed diagram, fig. 5, which represents the principle of the uniform chain, in which the oblique and horizontal tensions are borne by the chain alone; and as these are nearly equal, the power or section of the chain in either direction from point B must be equal also.

Fig. 5.

Here the weight of the portion of platform (A) to be supported is sustained by a single force B, from the main chain C, C. If, therefore, A = 8 tons, the rod B must be equal to that strain: fig. 6 is an example of the "resultant" principle: the portion of platform weighing, as before, 8 tons, is supported by two forces, viz. the oblique rod B, in the direction *b* B, and the horizontal force H. Supposing the angle at *b* to be 30°, the rod B will be strained with a power of (the weight × by cosecant of the angle *b*) = 16 tons, whilst the horizontal force (or weight × cotangent of the angle *b*) = 14 tons.

Now although in the first instance the actual tension on the rod B is only

Fig. 6.



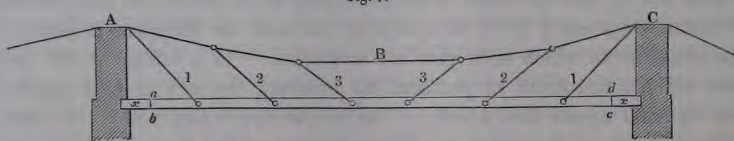
8 tons, and by that the weight is upheld, whilst in the second the total amount of sustaining power is $16 + 14 = 30$ tons, yet mark the difference of effect on the chains from which such rods are suspended. In a bridge of 160 feet span and 20 feet width of platform, for example, the area to be supported will be 3200 square feet, which, at 120 lbs. per square foot, will be 172 tons. With an angle of suspension of 15°, the tension on the chain in the uniform system will be $\frac{1}{2}$ weight $\times$ by cosecant of the angle of suspension, or $\frac{172}{2} \times 3{\cdot}86 = 332$ tons.

In the 'resultant' system (vide fig. 17, in which the entire series of strains have been worked out as shown in the Table), the extreme tension on the chain, or that due to the upper link, is 192·82 tons, the difference being made up in the tension on the horizontal beam, for which a proportionate section of iron is allowed; and this horizontal beam is not an extra item introduced merely to meet the strain, but is a component part of the system of framing of the platform, and as necessary to the whole as the platform of any ordinary suspension bridge.

Here, then, it is apparent that in fig. 5 the weight supported vertically causes a tension of 332 tons on the upper link of the example above mentioned, and that a proportional section of iron must be given to meet that strain; and not only that, but the same section must be continued throughout the whole series of links; whereas, as in fig. 6, the extreme tension on the chain, with an equal load, is only 192·82 tons, so that its section can be reduced in the proportion of 1 to 1·72 in the upper link, each link in the descending curve becoming lighter in proportion to the extent of diminution allowed; in addition to which advantages, the chain links, by the oblique position given to the suspending rods, are strained in the direction of their length, the most favourable to which they can be exposed. And moreover, if the weight of the whole series of chains, links, and vertical rods in the old system, be compared with the chains, oblique rods, and longitudinal beams of the 'resultant' system, for any given bridge, it would be seen that the two correspond as nearly as can be obtained in practice. This I have proved beyond doubt from the result of those bridges enumerated in the 20th paragraph, as remodelled on the 'resultant' system.

22. I will now detail the theory on which the 'resultant' principle is based. In the annexed fig. 7, A B C represent the chain of a tension bridge, the centre link of which is above the level of the railing; *a b d c*, the roadway,

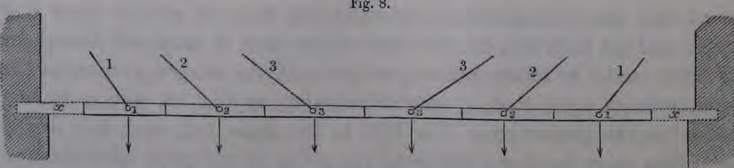
Fig. 7.



or suspended platform; the small portions *x x* being supported by the abutments. Let 1, 2, 3, 3, 2, 1, be the auxiliary oblique rods from the chain, the angle of those at the centre not being less than 25°, and those next the standards not greater than 45°. It is evident that the platform is entirely upheld by the auxiliaries, and it is to them therefore that our attention is first directed.

23. The auxiliary rods being by construction attached at equal distances, it is intended that each set shall bear an equal duty or tension; and as the stiffness of the platform to resist the force of gravity is uniform throughout, the whole series of oblique rods benefit equally thereby, and being thus common to all, it may be omitted in considering the strains on the auxiliary rods.

Fig. 8.



Suppose the platform to be divided into as many equal parts as there are oblique rods, thus giving to each rod an equal load, the points and attachment of which being the centres of gravity, we have six rods 1, 2, 3, 3, 2, 1, supporting the equal portions of platform having corresponding numbers.

24. The several portions of the platform acting by gravity whilst the sustaining force is oblique, a third force is necessary to preserve the whole in equilibrio. This force is, in the present system, tension in the horizontal line, as shown in the annexed fig. 9, acting from the standard towards the centre. These three forces, viz. vertical, oblique, and horizontal, being in proportion to the radius, cosecant, and cotangent of the angle of obliquity, the tensile force being that under consideration, it is necessary to connect the portions of the platform in fig. 8 in such a manner that the weight or force of gravity shall act freely, whilst the several parts are prevented from separating. Fig. 10 will show the meaning.

Fig. 9.

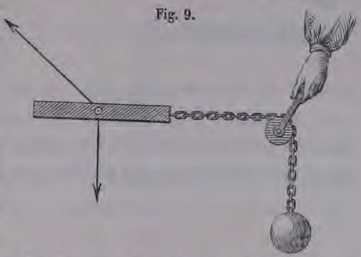
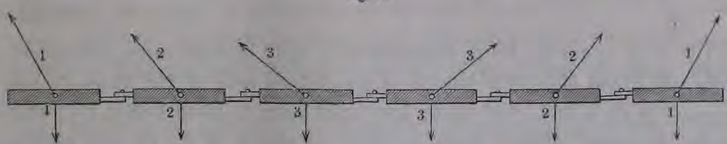


Fig. 10.

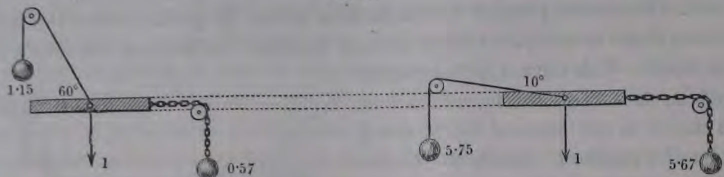


Here we have the tensions on the several portions 1, 2, 3, on one side, or half-span, counterbalanced by an equal amount of tension on the portions 3, 2, 1, of the opposite half: hence the greatest strain is in the centre, having the pull of $3 + 2 + 1$ acting on it, the connecting link between 2 and 3 being strained with the tension of $2 + 1$, and that between the parts 1 and 2 with the strain due to the part 1 only. Now the outer longitudinal beams of the system stand in the place of the connecting links of the above fig. 10, and are exposed to the varying tensile forces as described along the whole length, the amount of each of which admits of easy calculation; and whilst the precise spot of the greatest effect can be exhibited, the exact amount in every portion of the system can be accurately ascertained, and consequently provided for.

25. The following figs. 11 and 12 will show the relative tensions in the

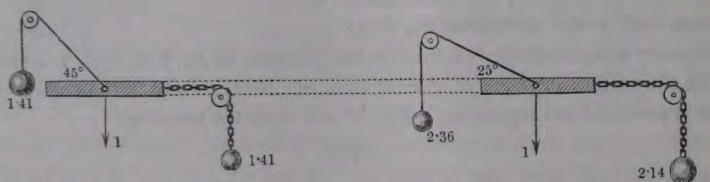
oblique and horizontal directions, in both Mr. Dredge's and the present 'resultant' systems; fig. 11 showing the strains where the oblique rod angles

Fig. 11.



vary, as practised by Mr. Dredge, from 10° to 60°, and fig. 12 the strains where the variation of the angles is only from 25° to 45°.

Fig. 12.



The force of gravity being represented by unity in both cases, the extreme difference in the amount of tension in the oblique rods of Mr. Dredge's combination is as 5 to 1, and in the horizontal beam as 10 to 1 (fig. 11), whilst in the 'resultant' system under adoption, as shown in fig. 12, the variation of tensions in either direction between the centre and standard is as 1·4 to 2·2, greatly to the advantage of the latter.

26. Now to apply the same principle of the composition of forces to the chain, so that the system may be in equilibrio. The span, width of roadway, its construction, the spaces between the oblique rods, and angle of the central one being determined, the weight to be assigned to each set of auxiliaries may be safely assumed at 120 lbs. per square foot of platform, including the weight of the structure.

27. The tension on the centre, or horizontal link, may be arbitrarily assumed, *i. e.* it may be made any proportion of the link at the point of suspension, thus tapering the chain $\frac{1}{3}$rd, $\frac{1}{4}$th, or 1^{nth} part of the sectional area of the upper link; for it is evident that by the arrangement of the angles formed by the first link from the centre and first set of oblique rods, the

strain on the centre may be = 0, or = 1000 tons, as is shown in the annexed figs. 13 and 14, where it is clear (fig. 13) that the tension on the centre link

Fig. 13.

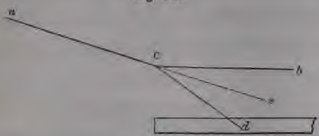
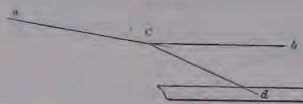


Fig. 14.

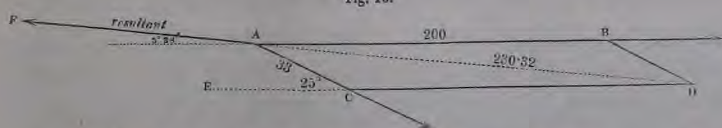


c b is increased or diminished as the line *c e* (the prolongation of *a c*) approaches nearer to *c b* or *c d*: the tension on *c b* will be a maximum when *a c b* are in one line, and a minimum (fig. 14) when *a c d* are in one line. The minimum of the central angle has, however, been practically determined to be 25°, with a view to the equalization, as far as practicable, of the strains on the entire series of oblique rods.

28. We have thus the means of assigning to the centre link any amount of power: its direction (horizontal) is known, as well as the tension and direction of the central oblique rods; we have therefore two forces, the magnitude and direction of which, with reference to each other, are known, from which to obtain a resultant, which shall be the first link from the centre: and here it must be borne in mind, that the height of the point of suspension, and consequently deflection, of the chain, depend on the power of the centre link; for the resultant, or 1st link from the centre, will form a greater or less angle with the horizon as its direction approaches less or more to that of the centre link; and the resultants arising therefrom, as the series of the chain draws nearer to the standards, will all be similarly affected.

29. The first resultant from the centre link and oblique rod is obtained from the following expression, fig. 15.

Fig. 15.



Suppose given A B = 200 centre link . . . }
A C = 33 centre oblique rod } the actual forces in the bridge designed for the Jumna at Agra,
∠ A C E or C A B = 25° . . . . . . }

to find the magnitude and direction of A D.

By Trigonometry,

$$
\begin{aligned}
AD^2 &= AC^2 + AB^2 - 2\,AC \cdot AB \cdot \cos : ABD. \\
&= AC^2 + AB^2 + 2\,(AC \cdot AB \cdot \cos : CAB.) \\
&= 1089 + 40000 + (13200 \times \cdot 906) \\
AD &= \sqrt{53048} = 230 \cdot 32 = \text{magnitude of } AD.
\end{aligned}
$$

Again,

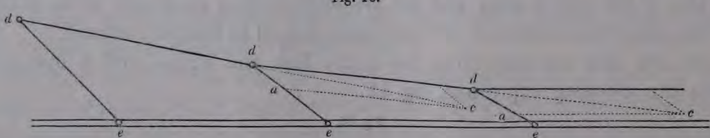
$$AD : \sin. BAC :: \begin{Bmatrix} CD \\ AB \end{Bmatrix} : \sin. CAD.$$

Sin. B A C = 25°	. . . .	log.	9·625948
A B = 200	. . . .	,,	2·301030
			11·926978
A D = 230·32	. . . .	,,	2·362332
Angle C A D = 21° 32′	. . . .	,,	9·564646

And angle C A B — angle C A D $= 25° - 21° \, 32' = 3° \, 28'$, or angle of first resultant A F with the horizon. Thus the magnitude and direction of the first link are found, and the link is a true resultant of the two forces acting at its lower extremity. In like manner can each link be ascertained till the series is complete; and thus a perfect system of links and auxiliaries will be obtained in equilibrio, under the maximum strain to which the structure can be exposed.

30. By reference to annexed fig. 16, the formation of the chain will be readily understood from the mechanical construction, as shown in the dotted lines, which are the forces taken from a scale of equal parts, and correspond with the results obtained by the mode of calculation above referred to.

Fig. 16.



The points of attachment *e*, *e*, *e*, of the oblique rods and platform are originally known, the span being divided into a number of equal parts: the length of the links or points *d*, *d*, *d*, are found by the annexed formulæ (Drewry, p. 172).

$\sqrt{\left(\text{deflection} + \frac{\text{deflection}}{3}\right)^2 + \text{semichord}^2}$ = semi-length of chain, which must be computed independent of the centre link. The semi-length thus obtained is to be divided into as many links as are required, which will of course depend on the number of spaces of the platform upheld direct from the standards (fig. 17). The deflection may be assumed any proportion of the chord line from $\frac{1}{10}$th to $\frac{1}{15}$th. In small bridges the latter is the best, as affording greater rigidity, with but little extra material; in large spans, perhaps a medium, or $\frac{1}{12}$th, will be found most practicable. In the above fig. 16, *a c*, *a c*, represent the strains on the main chains *a d*, *a d*, the tensions on the oblique rods, and *c d*, *c d*, the resultants.

31. In a bridge on the 'resultant' system of 500 feet span and 24 feet width of roadway, if the chain were made to taper at the centre to $\frac{1}{5}$th the section of the link at the point of suspension, which in this case would be equivalent to the tension of 1014 tons, the central link would have nine times the strength that in the extreme, or Dredge's tapering system, would have been assigned to it, whilst from the position of the resultant link and collateral oblique rods, the iron in the centre does not hang as dead weight tending to produce vibration by the slightest cause, as in the uniform system, but is kept under the dominion of tension drawn in the direction of its length, and thus preserved steady and rigid.

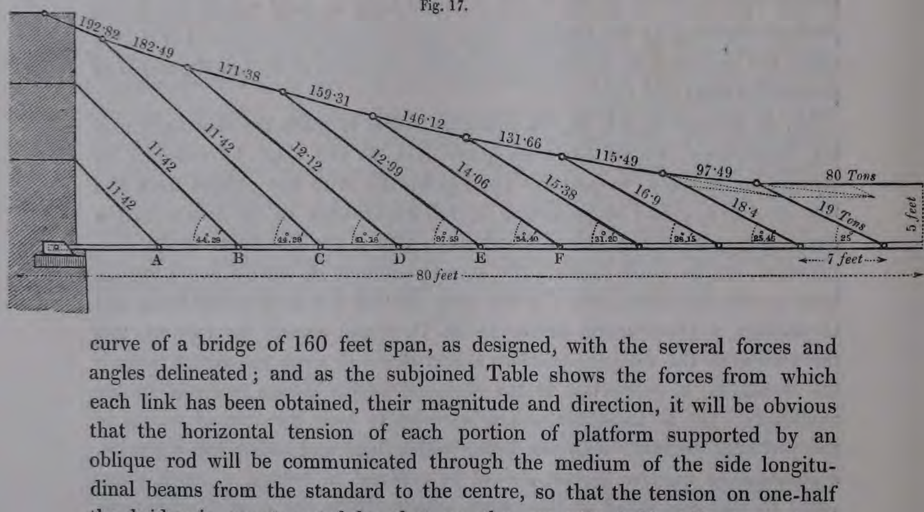
32. In paragraphs 24, 25, the principle that is to guide the construction of the longitudinal beams has been given, viz. as the third force acting by tension horizontally, to preserve the equilibrium with the oblique force and that of gravity; and in paragraph 9, full explanation of the reason of the above arrangement has been entered into; and it has also been shown, that provision can be made to meet the several amounts of tension acting on the beam in the horizontal line. If this were all that the longitudinal beam had to perform, a construction similar to fig. 10 would answer the purpose, and the section of the different portions might diminish from the centre towards the standards, in proportion to the variation of the strains produced by the auxiliaries; but as these beams are intended to bear the vertical weight of the platform, together with the heavy traffic load and other contingencies, a compact or uniform section should be retained in bridges of small span, equal to that demanded at the centre, which will be the most advantageous to the system, and facilitate the actual construction, though in larger spans a considerable reduction of section may be effected between the centre and standards.

33. The 'resultant' system, as above elucidated, cannot surely fail to present many valuable points for recommendation, professing, as it does, practically to coincide with the theoretical and analytical conclusions of the

author of the Memoir under notice; and, moreover, whilst it is divested of the positive defects of both the systems which have been simultaneously reviewed, a powerful resultant is obtained from the composition of the advantages or forces of each of them. From what has been shown above, it will be clear that in a condemnation of the 'resultant' system, the uniform must be included, the latter being nothing more than an extreme of the general system, in which the strain on the chain is a maximum, and the horizontal tension 0; whilst the system of Mr. Dredge in a way aims at, but does not attain, the opposite extreme, where the tension on the chain is a minimum, and that on the horizontal line a maximum.

34. It now remains to show another advantage of the 'resultant' system with a diminishing chain. The annexed fig. 17 is the constructed resultant

Fig. 17.



curve of a bridge of 160 feet span, as designed, with the several forces and angles delineated; and as the subjoined Table shows the forces from which each link has been obtained, their magnitude and direction, it will be obvious that the horizontal tension of each portion of platform supported by an oblique rod will be communicated through the medium of the side longitudinal beams from the standard to the centre, so that the tension on one-half the bridge is counteracted by that on the opposite half: this amount of tension in a loaded bridge of large span is very great (600 tons in a span of 500 feet, and 24 feet wide), being the sum of all the horizontal tensions A + B + C + D + E, &c.; and as the ends of these side beams are securely built into the standard masonry, the swaying of the structure from side to side, or undulation vertically under the influences of storms, or other ordinary destructive causes (excepting to a very slight extent), is prevented. At the proof trial of the Ballee Khâl bridge, 250 feet span, after its reconstruction on the 'resultant' principle, the transit of a large elephant, and a 24-pounder siege gun with all its appurtenances, caused no sensible vibration, or visible depression, whilst at the conclusion of the ceremony the entire platform was covered with a dense crowd of villagers, who, on the departure of the Governor and suite, came to witness the opening, and congregated as far as they were able to one side of the bridge, thus giving fair proof of the stability and rigidity of the structure.

Table showing the Forces of Links and Oblique Rods, with the Resultants obtained therefrom.

Forces composing the Resultants, or links of chain.	Forces due to chain.	Angles of oblique rods with horizon.	Cosecants of angles of oblique rods.	Angles of oblique rods with chain.	Weight of one space of platform.	Angles of chain links with horizon.	Calculated Resultants, or tensions on chain links.	Position of links.
	Tons.				Tons.			
Centre link	80	....	....	....	....	....	....	Centre link.
Centre oblique rods .	19	25°	2·366	25°	8	5° 45′	97·49	1st link from centre.
1st link from centre .	97·49							
2nd set of oblique rods	18·4	25° 46′	2·3	20° 1′	,,	8° 58′	115·49	2nd link ,, do.
2nd link from centre .	115·49							
3rd set of oblique rods	16·9	28° 15′	2·113	19° 17′	,,	11° 24′	131·66	3rd link ,, do.
3rd link from centre .	131·66							
4th set of oblique rods	15·38	31° 20′	1·923	19° 56′	,,	13° 27′	146·12	4th link ,, do.
4th link from centre .	146·12							
5th set of oblique rods	14·06	34° 46′	1·758	21° 13′	,,	15° 17′	159·31	5th link ,, do.
5th link from centre .	159·31							
6th set of oblique rods	12·99	37° 59′	1·624	22° 42′	,,	16° 57′	171·38	6th link ,, do.
6th link from centre .	171·38							
7th set of oblique rods	12·12	41° 18′	1·515	24° 21′	,,	18° 31′	182·49	7th link ,, do.
7th link from centre .	182·49							
8th set of oblique rods	11·42	44° 28′	1·427	25° 57′	,,	20°	192·82	8th link ,, do., or upper link of chain.

35. If, therefore, as demonstrated by the Rev. Mr. Pratt, the quantity of iron calculated to resist a certain dead weight be the same for bridges of equal span and width, and of equal strength, whether the metal be distributed, as in the uniform system, or as in the 'resultant,' it surely is no small advantage in favour of the latter, that by construction it is defended from the severe trials to which all bridges, even when unloaded, are exposed, from the momentum which a comparatively light body obtains when put in motion.

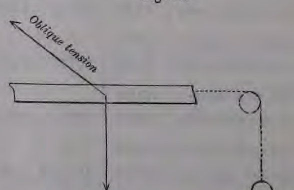
36. The extra aid usually applied to suspension bridges on the uniform system, for the purpose of stiffening them, has been found absolutely necessary, and duly commented on in paragraphs 4 and 5: and whilst such means are almost indispensable in the old system, to compensate for vicious construction, in the 'resultant' system they form an essential part of the principle; and considering the results of the experiments on a full-sized scale (*vide* the end of these notes), the favourable reports on those bridges actually constructed on the 'resultant' principle, together with the theoretical soundness of the details, it appears neither reasonable nor consistent to object to it, since it has every good quality that such a structure can require to recommend it.

RESULTS OF A SERIES OF EXPERIMENTS INSTITUTED FOR THE PURPOSE OF TESTING THE NEWLY PROPOSED RESULTANT TAPER CHAIN PRINCIPLES.

Plate XV.—Fig. 1 is illustrative of the first experiment, which was intended to test the theory of a system based on the 'resolution of forces,' as explanatory of the proposed construction of the Agra bridge.

The idea of compression in the horizontal line having, from actual proof, been deemed untenable in bridges of any ordinary span, the opposite power of tension has been admitted as the third in the series to produce an equilibrium jointly with those of gravity, and the tension in the oblique direction from chain to platform, thus, fig. 18. The oblique and horizontal force in a series bearing theoretically a certain proportion to each other with reference to the obliquity of the former, the weights at each point being uniform, this experiment was instituted to prove practically how far that theory was correct.

Fig. 18.



It was also intended to illustrate practically the theory relative to the position and power of the chains, the links of which are calculated to be true resultants from the two forces immediately below them in the chain, viz. the link and oblique rod attached to the lower extremity of that resultant.

Fig. 1, Plate XV., also shows the experiment to prove whether, individually

Sketches illustrative of Three Experiments undertaken to test the Taper Chain Resultant System of Iron Suspension Bridges.

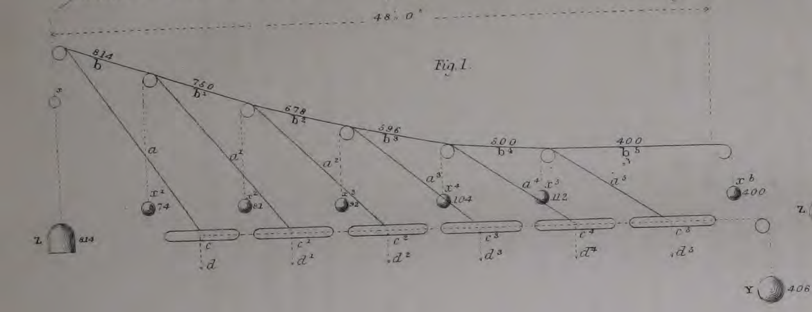


Fig. 1.

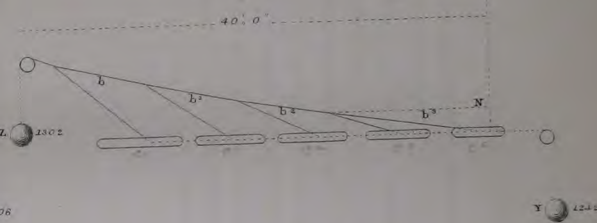


Fig. 2.

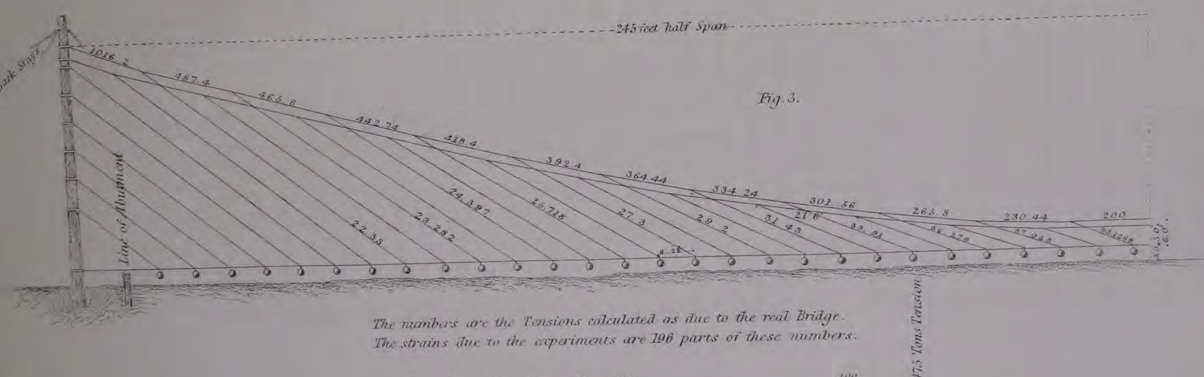
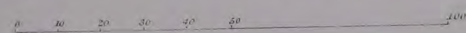


Fig. 3.

The numbers are the Tensions calculated as due to the real Bridge.
The strains due to the experiments are 196 parts of these numbers.



or collectively, the several sets (three forces applied to any point to produce equilibrium) of forces which may be applied to any single rod, link, or the entire series of rods and links, will be proportionate to the different strains, which are those calculated as due to the parts of a bridge of 100 feet span, 16 feet wide, constructed on the above principle.

The experiment was on full scale as regards heights and distances, but formed of material $\frac{1}{220}$th of the strength of the real bridge, the uniform weights at the points of junction of the oblique rods with the platform being in the same proportion, allowing 120 ℔s. per square foot.

The point of suspension is 2 feet from the centre of the standard, making the half-span of the chain 48 feet.

The power of the centre link, by actual construction, was made equal to $\frac{1}{4}$th that of the upper link, or whole amount of tension which would be due to a uniform chain, and the angle of the central oblique rod determined to be 30°, the deflection being $\frac{1}{11}$th.

The chain was not at first attached, but the forces necessary to preserve equilibrium at the points of attachment of the oblique rods with the platform, first attended to, as follows, each of the portions of platform (c, c^1, c^2, &c.) being separate at first, and afterwards flexibly connected. (Plate XV. fig. 1.)

To the portion c, with a weight d of 56 ℔s. was attached a single rod a, passing over a pulley at the point of suspension; a weight x, and part of weight Y, passing over a pulley in the horizontal line, were added in such proportions till they produced an equilibrium, *i.e.* till the portion of platform c was made horizontal by the joint effects of the two weights x and Y.

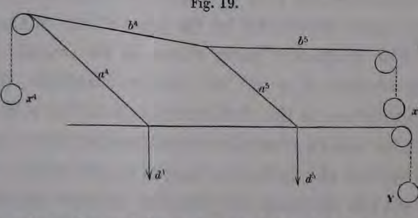
The subjoined Table shows in its several columns what the proportions of the weights (x, x^1, x^2, &c., and Y) should be, theoretically calculated, to produce equilibrium at the different points as the rods were successively attached; and it also shows what the actual weights were particularly applied in succession, as well as the collective results on the whole series, with the differences.

At the distance of 7 feet the oblique rod a^1 was attached to a second piece of platform c^1, with its weight of 56 ℔s., which latter was also connected to the piece c flexibly; the weight x^1, appended to the rod a^1, and weight Y, increased till the equilibrium was produced, or both pieces of platform c, c^1 were in a horizontal line. In like manner were all the obliques, a^2, a^3, a^4, a^5, attached to the several portions c^2, c^3, &c., of platform, and the weights added and corrected: when the whole series was complete, the weight Y had attained its maximum. The Table will show the differences between the actual weights Y, Z, x^1, x^2, &c., and the numbers on the Plate, which are those mathematically calculated as due to the several rods and beam.

The result shows that the whole were increased slightly beyond the calculated amounts; but this may be attributed to the friction of the chains upholding the oblique rods, which passed over cast iron pulleys, 9″ diameter. It will be observed, however, that the increase was proportional: thus the originated calculated weight x^1, due to the oblique rod a^1, was 74 lbs., but, to produce equilibrium, required to be increased to 95, and the calculated total amount of weight Y was 406 lbs., afterwards practically requiring 519; but the numbers 74 and 406 are relatively proportional to 95 and 519.

To prove the proportions due to the chain links in connection with the rest of the parts, the oblique rods were severally disengaged from the pulleys, and attached to the chain as follows. The rod a^5 was first attached to the centre link b^5, the outer end of which was fixed to a chain passing over a pulley, and to which was appended weight x^6. The lower end of the link b^4 was likewise attached to the junction of the two rods, and its upper end to a chain passing over a pulley with weight x^4 appended, the intermediate pulley and weight x^5 being removed. In this position was remarked the amount of the weights required to produce equilibrium, and what proportion x^4, which denoted the tension on link b^4, bore to the numbers, mathematically calculated: the result of the whole is shown in the Table, and the annexed sketch, fig. 19, the position of the rods at this period, b^4 being a true resultant of b^5 and a^5. Each other link, b^3, b^2, &c., was then added in succession, the weights x^4, x^5, &c., being withdrawn in turn, and that attached to the link under investigation being increased as the experiment approached the upper link b, when the weight Z denoted the total tension on the upper link. (Plate XV.)

Fig. 19.



Thus was shown the separate tension on the oblique rods, the horizontal tension on longitudinal beam, and the tension on each link of the chain: the results, as compared with theory, are noted in the Table, and are satisfactorily approximate to each other.

It was stated in the Report of the Committee on the Ballee Khâl bridge, and referred to in the ninth paragraph of my statement on the resultant system, before alluded to, that the power of the longitudinal beam at the centre, added to the power of the centre link, should together be nearly equal to the power of the upper link; so that whatever power was taken from the chains in the centre, should be compensated for in the longitudinal beam. Now the result of the experiment entirely coincides with that opinion, and confirms the view taken of this part of the construction. The total corrected amount of weight Z was was 1086 ℔s., and the sum of weights x^6 and Y, or $572 + 519 = 1091$ ℔s.

Experiment 2nd, fig. 2, Plate XV., was proposed by Colonel Forbes, on Mr. Dredge's extreme oblique principle, with the sole exception that the central portion of the roadway beam formed the horizontal connection between the first slanting links on each side of the centre, thus: as in the fig. 2, as before, c, c^1, c^2, &c. denote the platform, b, b^1, b^2, the chain, the lower link of which is attached near the centre to the longitudinal beam at c^3. In this position only can Mr. Dredge's theory of a vanishing strain existing in the centre link (N, dotted line) be granted; but at the same time the roadway beam must be equal, nearly, to the full section of iron in the upper link, as the result proved. The weights Z and Y were alone necessary for this experiment, the weights d, d^1, d^2, d^3, being, as before, $\frac{1}{2}$ cwt. each.

The span of this half-curve was only 40 feet, yet it required 1242 ℔s. at Y, and 1302 ℔s. at Z, to produce equilibrium, being a greater weight than in the former experiment, in consequence of greater tension being called into action by the greater obliquity of the rods; and a proof that in Mr. Dredge's construction there is not iron enough in the centre of the longitudinal beam to resist the tension existing there. This experiment showed much more rigidity than the former one, being more powerfully acted on; but to have manufactured it sufficiently strong to resist the tension, would have entailed a heavier outlay than the former.

There is no doubt but that this construction of making the longitudinal beam act centrally as part of the chain would tend to stiffen the structure, and might simplify the details in small spans; but in large spans, where the centre link is of great substance, and with a double chain, practical difficulties occur which would render the centre link a necessarily distinct feature, and prevent its absorption into the roadway beam.

The reason why the chains are drawn tangent to the railing is to enable the railing to be placed centrally under the chains; for if the chains were tangent to the roadway, though there would be a decrease in the height of the standards, there would be a loss of 2 feet in width of platform; for with a wide chain dipping below the railing, the stanchions supporting it must be placed 1 foot on each side, within the central line of the chain, in order to avoid contact with it; and an extra 2 feet of platform is more expensive in its consequences on the amount of iron than an additional 4 feet of masonry on the standards.

Experiment 3rd, of which fig. 3, Plate XV., is illustrative, was a construction on the resultant principle, similar to Experiment 1, carried to a much larger extent. Fig. 3 shows only one-half of it, as it was an entire curve of 490 feet between the points of suspension, the lengths of the rods and beam, heights and distances, being to a full scale, whilst the sectional area of the iron was $\frac{1}{196}$th part of reality. The sections of the whole of the parts are given, and proof calculations that each was correctly proportional to the full sections of the actual bridge. The standards were formed of spars, firmly supported by struts in front,[1] and stayed back with ropes and chains, the latter having tackle on them to correct the perpendicularity of the masts, should they yield to the load.

The horizontal beam was upheld by forty-four rods from the chain and six direct from each standard; the chain double, tapering in the centre to a power equal to $\frac{1}{5}$th the upper link.

The angle of the centre oblique rod 25°, and that of the one next the standard 38°; so that there was only a difference of 13° between the two extremes, divided amongst twenty-eight points, or a difference of tension between the extremes in the proportion of 2·63 to 1·62.

The deflection of the chain was equal to $\frac{1}{12}$th the span.

The section of the longitudinal beam at the centre, added to the section of the centre links, was equal to the sectional area of the upper links of the chain.

The whole of the experiment being, as before said, $\frac{1}{196}$th part of reality, is a model of the curve which was designed for the Agra bridge, the whole of the details of which are given in this Memoir, and the result of this experiment will go far to prove the theory advanced to be correct.

The calculations show the proportional load for the experiment to be

[1] Left out in drawing, to prevent confusion.

1352 lbs., at the rate of 120 lbs. per square foot of platform, to be uniformly distributed over fifty-six points. This was done by slinging a basket at each point, and gradually loading them up to the amount of 57 lbs. each.

When loaded with 24 lbs. in each basket, or 51 lbs. per square foot, exclusive of weight of experiment, the deflection in the centre, after the masts were made upright, was $1\frac{3}{4}$ inch only in the centre.

When an extra load of 16 lbs. per basket, making in all 40 lbs., or $84\frac{1}{2}$ lbs. per square foot of platform, the deflection in the centre was $5\frac{1}{2}$ inches, and midway between the centre and standards, on one side $1\frac{1}{2}$ inch, and on the other $2\frac{1}{4}$ inches, on account of the greater flexibility of one mast than the other. When the full load of 57 lbs. on each point, or 120 per square foot, was put on, the deflection was $13\frac{1}{8}$ inches in the centre. This load was allowed to remain on three days: it was subsequently unloaded and reloaded several times with nearly the same results; and after the lapse of seventeen days from the period of its first being loaded, when all the weight was taken out of the baskets except 24 lbs., which is proportional to the weight of the suspended platform of the real bridge without the traffic weight, the longitudinal beam sprang up to within $\frac{3}{8}$ths of an inch of the horizontal line in which it was first constructed.

Thus was this very extended curve, formed of such exceeding slender material, not any of which could be proved before it was put together, found equal proportionally to the greatest amount of the traffic load that could on any extraordinary occasion come on the bridge without derangement of any of its parts: the combination appeared as stiff under the load as could reasonably be expected with such slender wires, and fully bore out the results detailed in Experiment No. 1, and the mathematical demonstration of the powers of the bridge, as set forth in the specification of the Agra bridge.

Subsequent to the above detailed loading, I continued adding weight to the baskets, and correcting the masts as well as the power of the tackle enabled me to do, till the weight in each basket amounted to 81 lbs., when the longitudinal beam was torn asunder at the distance of 25 feet from the centre, and the whole immediately buckled up. The breaking weight was therefore 174 lbs. per square foot of platform, or a tension of 15 tons per square inch of that slight material, the weldings of which were with difficulty made, and the strength of which there was no means of proving.

I cannot imagine any further proof to be necessary of the efficacy of such a system as has been proposed, manifestly having for its object the avoidance of the defects of both the uniform and extreme oblique systems, combining the strength and solidity of the former with the rigidity, economy, and more advantageously scientific construction of the latter.

In this construction, admitting the action of tension in every direction, and where the rods and bars are drawn in the direction of their length, the full amount of tension that can possibly affect every part of the structure can be accurately ascertained, and thus certain data are afforded from which to proportion the sectional areas of every part of the bridge.

Scantlings of Rods of Experiment No. 3.

Each chain.	Upper link	$\frac{15}{32}$	of one inch.
	2 ,,	$\frac{29}{64}$	
	3 ,,	$\frac{28}{64}$	
	4 ,,	$\frac{27}{64}$	
	5 ,,	$\frac{26}{64}$	
	6 ,,	$\frac{25}{64}$	
	7 ,,	$\frac{24}{64}$	
	8 ,,	$\frac{23}{64}$	
	9 ,,	$\frac{22}{64}$	
	10 ,,	$\frac{20}{64}$	
	11 ,,	$\frac{19}{64}$	
	12 or centre	$\frac{18}{64}$	

Oblique rod $\frac{1}{8}''$ diameter.

Longitudinal beam at centre $1'' \times \frac{3}{16}''$.

,, ,, 7th space from centre $1'' \times \frac{9}{64}''$.

EXPLANATION OF THE RELATIVE PROPORTION BETWEEN THE EXPERIMENT AND THE REAL BRIDGE.

Full section of two chains one side of the real bridge.

Upper link, 17 bars $2'' \times 1'' = 34'' \times 2'' = 68$ square inches.

Diameter of experimental upper link, $\frac{16}{32}$ of one inch.

Area of which $\cdot 178$ and $\cdot 178 \times 2$ ch. $= \cdot 346$ section of two chains:

$$\cdot 346 \times 176 = 67 \cdot 8, \text{ or section of real bridge.}$$

Area of platform, real bridge, $468 \times 11 = 5148$ square feet:

$$5148 \times 120 = 617760 \text{ lbs. on real bridge.}$$

$$\frac{617760}{196} = 3152 \text{ lbs. total load for Experiment.}$$

$$\frac{3152}{56} = 57 \text{ lbs. on each point of Experiment.}$$

GENERAL ELEVATION OF THE TAPER CHAIN TENSION BRIDGE O
THE RIVER JU

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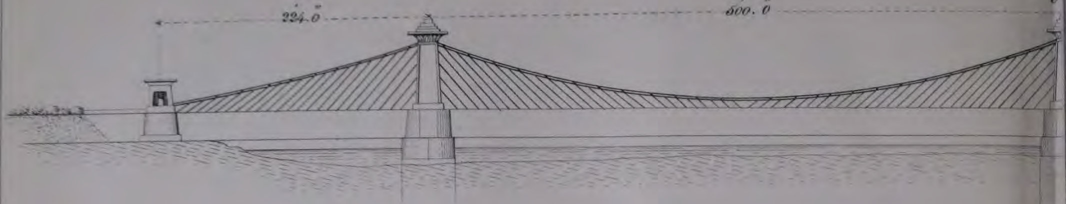

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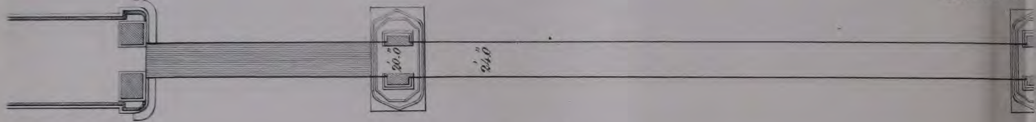

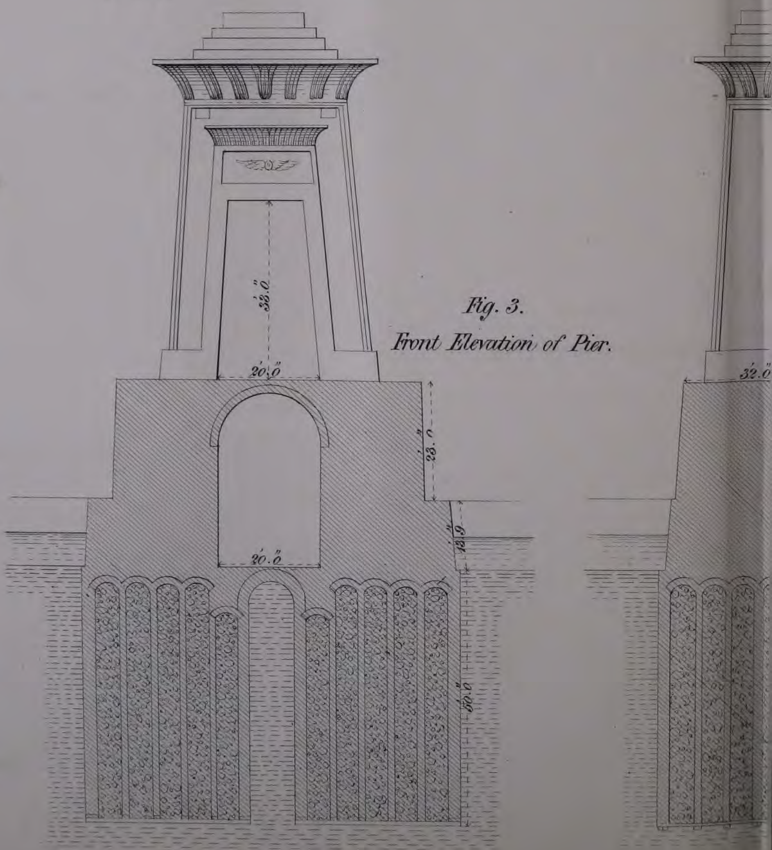

Fig. 3.
Front Elevation of Pier.

THE "RESULTANT" SYSTEM, PROPOSED TO BE ERECTED OVER
NA AT AGRA.

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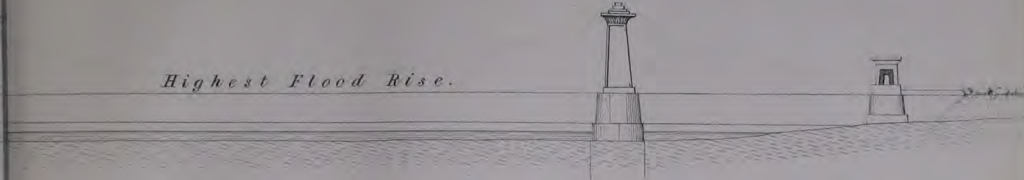

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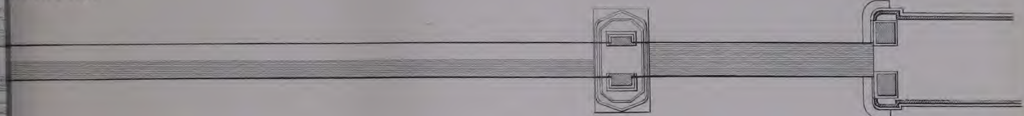


Fig. 9.
Plan of one Block, or Half Base of Pier.

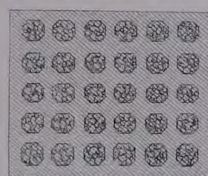


Fig. 5.
Plan of Pier.

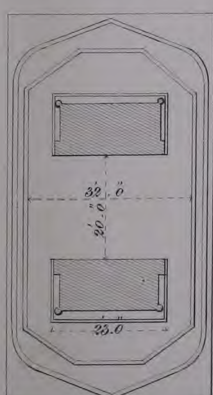


Fig. 4.
Side Elevation of Pier.

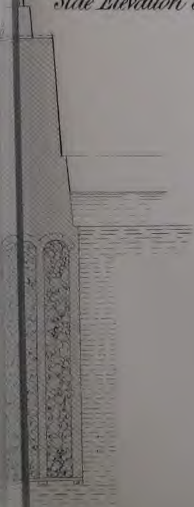
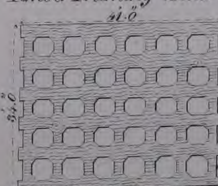


Fig. 10.
Plan of Timber Framing under Blocks.



Scale for Fig.s 1 & 2.
0 50 100 200 300 400 Feet

Scale for Fig.s 3. 4. 5. 9. & 10.
0 5 10 20 30 40 50 60 70 80 90 100 Feet

Area of oblique rods of real bridge 2·405 each.

Diameter of rods of Experiment $\frac{1}{8}''$ or sectional area ·012:

$$\cdot 012 \times 196 = 2\cdot 352,$$ or very nearly the section of real bridge.

Sectional area of longitudinal beam of real bridge at centre, 37 inches; remainder 27″ beyond the 7th oblique rod.

Sectional of experimental beam at centre $1'' \times \frac{3}{16}'' = \cdot 188$;

and $\cdot 188 \times 196 = 36\cdot 848$, or nearly the section of real bridge.

Remainder of section, $1'' \times \frac{9}{64}'' = \cdot 141$ at the 7th rod:

$\cdot 141 \times 196 = 27\cdot 636$, as nearly as possible the section of real bridge.

Table explanatory of the previously calculated Theoretical Tensions, and subsequently practically proved Results, on an Experiment undertaken to test the Taper Chain 'Resultant' System.

	Oblique Rod Forces.			Chain Link Forces.		Total Tension Horizontal Line.				Total Tension Upper Link.			
	Previously calculated.	Practical result.	Difference.		Practical result.		Previously calculated.	Practical result.	Difference.		Previously calculated.	Practical result.	Difference.
x or a	68			b	814								
x^1 ,, a^1	74	95	21	b^1	750								
x^2 ,, a^2	81	102	21	b^2	678								
x^3 ,, a^3	92	107	25	b^3	596	Y	406	519	113	Z	814	1068	272
x^4 ,, a^4	104	132	28	b^4	500								
x^5 ,, a^5	112	145	33	b^5	400								

Specification of the Details of Construction of a Tension Bridge on the 'Resultant' System, designed to be erected over the River Jumna, at Agra, in Bengal.

Plates 1 and 2 are illustrative of the design and details: the design consists of two entire curves of 500 feet each between the centres of the standards, and two half-curves of 224 feet each, (figs. 1 and 2, Plate 1.) The platform, 25 feet between the centres of the longitudinal beams, or 24 feet clear traffic-way between the railing, fig. 2, Plate 1; the openings through the standards being 20 feet clear.

Figs. 1, 2, Plate 3.—The chains to be four in number, two on each side, one vertically above the other, all the links being 21′ 6″ long, except the upper and centre, which vary by the nature of the construction, as shown in fig. 1, Plate 3. The bars composing the links are each $2'' \times 1''$, and as there are seventeen bars in the upper link of each chain, and six in the centre link of each, the strength of the entire chains at the point of suspension will be equal to 1224 tons, and at the centre 432 tons: the powers of these chains are to meet the respective tensions of 1014 and 400 tons, as shown in fig. 1, Plate 2. The weight per square foot of platform has been assumed at 150 lbs., and 9 tons per square inch of iron has been allowed for the tension.

The curve has been projected on the 'resultant' system, as explained in paragraphs 27, 28, a duty or strain (under a fully loaded platform) of 400 tons having been assigned to the centre links. The first link from the centre is a resultant of a tension of 200 tons in a horizontal direction and 33 tons obliquely, (being the tension of the centre rods or 14 tons weight of platform × natural cosecant of 25°); the angle subtended by the two forces being also 25°. The resultant, as per expression in paragraph 29, is 230 tons, rising 3° 28′ above the horizon: in the same way have the whole been computed till the total tension at the point of suspension was found to be 1014 tons.

The deflection of the curve is $\frac{1}{10}$th of the chord line, and the centre links raised well above the railing, by which the latter are enabled to be erected in the same plane with the longitudinal beams, adding to the rigidity of the whole.

OBLIQUE RODS.

Here one of the great advantages of the oblique system is apparent, for nearly $\frac{1}{5}$th of the platform is supported by rods direct from the standards, and that not in the mode formerly adopted of connecting the whole of the direct rods to the point of suspension, but distributing them in a parallel position, whereby they are all equally strained, the appearance is more uniform, and their attachment to the standards and to the rods in the opposite direction more simple and effective. Thus, though the total length of suspended platform is 468 feet, the weight of only 378 feet will affect the tension on the chains, fig. 1, Plate 1.

The oblique rods depend in pairs from each chain alternately, and are attached to the outer extremities of the link-bolts, each pair being composed of two bars of $2\frac{1}{4}'' \times \frac{1}{2}''$, which gradually approach each other till below the level of the hand-rail bar, where they are coupled, and a single rod, $1\frac{3}{4}''$ diameter (equal to the section of the two upper bars), passes down to the longitudinal beam, between the plates of which it is nutted behind a socket-bolt of wrought iron, which is self-adjusting, so that the oblique rod easily accommodates itself to the required angle. *Vide* figs. 6, 7, 8, 9, Plate 3.

The extreme tension on the centre oblique rods is, as above stated, 33 tons, for which a section of 2·4 square inches on each side, or total of 4·8 square inches, is provided, being equal to a power of 43·2 tons. The portion of platform upheld by each set is 8′ $2\frac{1}{2}''$.

LONGITUDINAL BEAMS

Of the section shown at fig. 14, Plate 4, and to meet the entire amount of horizontal tension for a length of 60 feet on each side of the centre, are strengthened by plates, as shown in fig. 15.

The sectional area in each double beam is 33 inches, and allowing a deduction of 7 inches for bolt-holes on each side, there remains a section of 26 square inches on each side, or 52 inches in the total horizontal power, = 468 tons.

Admitting no assistance from the capacity of the platform to resist compression, it will be found that the total tension on the longitudinal beam at the centre is 610 tons (the product of the weight of half the bridge × mean of cotangents of angles of oblique rods). To meet this tension, which is 142 tons, in excess of the power of the section of fig. 14, provision is made by the additional plates, fig. 15, which are bolted to the beam, and contain 10 square inches on each side, making a total section of 62 square inches for 60 feet beyond the centre each way = to a tension of 648 tons.

The beams might be made to taper considerably between the centre and standards, to be theoretically correct; but as the weight of the platform has to be borne vertically, and some practical inconvenience might be experienced in fashioning iron of different scantlings into the beam, the difference in weight by the greater uniformity of section is assumed to be a matter of such little importance as to justify the mode of construction here adopted.

Fig. 18 shows a joint or coupling.

During the progress of erection, the longitudinal beams, when all coupled, will require some mode of adjustment to render the line perfectly horizontal; the beam is first coupled from the centre, and as the attachment of the oblique rods progresses simultaneously, the beam is kept straight by their action; but in order to adjust the ends at the standards, an arch in the masonry, fig. 25, Plate 5, is left, and the cast box which receives the ends of the beam having a long slot or groove in it, the bolts which pass through have play till the line is complete, when the nuts can be tightened and the slot filled up with hard wedges. Fig. 4, Plate 3, shows how the ends of the iron beams are secured in the masonry.

Transverse Beams need not necessarily be of iron, but are here so designed on account of the greater lightness and durability of the material. Fig. 5, Plate 4, shows the construction, and fig. 16 the section of the iron employed. They are of T iron with a rise of 4 inches in the centre: in the length of the platform every third beam only is trussed in the way shown in fig. 5; the remainder are plain. The ends of the beams are let into cast boxes, figs. 11, 12, 13, which are not, as formerly, hung on to the side of the longitudinal beam, but rest on it, though not bolted, and are capable of adjustment right and left, by means of the lower ends of the cast boxes which slide between the longitudinal beams. The struts of the trusses are cast with a slot to receive two central longitudinal beams which are of light scantling compared with the outer, 4″ × 1″; they rest in the strut slots, and serve to reduce the bearing of the transverse beams that are not trussed. The table of the T iron is drilled to receive the plank spikes.

Retaining Rods are provided in two sets, one for the lower ends of the chains, and the other for the end of the longitudinal beams of the half-curves at the ends of the bridge. Fig. 19, Plate 5, shows the arrangement; the link next to the central one forms the termination of the half-curve, and from this, retaining chains are taken down to their moorings. In each of these links next the centre on either side are seven bars, 2″ × 1″, to the ends of which are attached six wrought iron coupling plates, curved on the under side and resting on cast saddles let into the stone-work of the masonry: to the lower ends of the plates are bolted five retaining rods, 3″ × 1″ (equal in section to the seven bars of the link, 2″ × 1″), which are carried down to the chambers, as shown in fig. 22, Plate 5, and fig. 8, Plate 2, where they are secured behind cast iron frames abutting against radiating stone-work, by means of wrought iron keys and wedges.

The amount of tension at the centre of the longitudinal beam has been shown to be 610 tons, or 305 on each side: to meet this, a proportional section of iron in the retaining rods is required, which is obtained by four parallel lines of bars, $2\frac{1}{4}$″ × 1″, with four bars in each line, having a total section of 36 square inches = 324 tons. Their mode of attachment to the end of the beam is shown in figs. 20, 21, Plate 5, and these rods are secured similarly to those from the chain behind cast iron frames, figs. 26, 27, Plate 5.

Railing is of cast iron stanchions and wrought iron diagonal braces. The feet of the stanchions are firmly bolted between the sides of the longitudinal beams, figs. 5, 10, Plate 4, and the diagonal braces are bolted above and below through eyes cast on the stanchions, and are adjusted to a state of rigidity by means of a central wrought iron ring with inner cast bearing plate, through which the ends of the diagonals pass and are screwed up tight. Fig. 24, Plate 5, shows the method: thus a line of stiff bracing along the whole bridge is obtained, which will add very much to the steadiness of the bridge.

Planks, of 3-inch teak, spiked and screwed to the transverse beams, and crossed by diagonal road track bars, $2\frac{1}{2}$″ × $\frac{3}{8}$″, for their protection against wear by traffic, whilst such bars add considerably to the stiffness of the platform, and are a lighter and better covering than metalling: 16 tons is the weight of the iron road tracks for one curve, whilst 127 tons would be about the weight of 4 inches of stone or brick-metalling for the same space.

The sides of the planks to be dowelled together, and a longitudinal sleeper screwed firmly down just within the railing, which will tend to preserve them from wheels, or to retain metal, should it be hereafter put on to the platform. Fig. 5, Plate 4, shows a section of the platform.

Fig. 3, Plate 3, shows a general elevation of one side of the bridge, with section through the standards, showing many details which have not been described, such as the cast saddles for carrying the chains, the mode of carrying the direct oblique rods through the standards, the couplings of the oblique rods, the railing, &c.

The detail of the iron-work, with the weights of each part, are as follows:

	lbs.	Tons.	Cwt.	Qrs.	lbs.
Main chains of one curve of 500 feet, including the tower links, bolts, nuts	169,425				
or,					
Weight of main chains, as above, for the entire bridge	508,275	226	18	0	19
Oblique rods of one curve, including coupling plates, self-adjusting socket-bolts, nuts, and the horizontal rods in standards	59,777				
or,					
Weight of oblique rods for entire bridge	179,331	80	1	0	19
Longitudinal beams for one curve, including the outer and central beams, couplings, bolts, nuts, and fastenings in standards	153,264				
or,					
Entire weight of longitudinal beams for whole bridge	459,792	205	5	1	4
Transverse beams for one curve, including truss rods, bolts, and nuts	75,753				
or,					
Weight of transverse beams for entire bridge	227,259	101	9	0	11
Retaining rods with couplings, bolts, keys, nuts, and wedges	78,208	34	18	1	4
Railing and roadway track bars for one curve, including diagonal braces, bolts, spikes	56,892				
or,					
Weight of railing and road track bars for entire bridge	170,676	76	3	3	16
Total wrought iron-work		724	15	3	17
CAST IRON.					
Main saddles	40,320				
Saddles for retaining rods and oblique rods	7,600				
Cast boxes for transverse beams and abutment boxes	45,920				
Transverse beam struts	6,840				
Frames for retaining rods	53,760				
Tie-rod plates	600				
Railing stanchions and adjusting plates	61,500				
Total weight of cast iron	216,540	96	10	2	24
Entire weight of iron-work of bridge		821	6	2	13

I may add in conclusion, that having calculated the weights of a bridge of the same span, width of platform, and deflection on the uniform system, the result is as follows:

	lbs.	Tons.	Cwt.	Qrs.	lbs.
Main chains with couplings and bolts	1,188,551				
Suspending rods with shackles, stirrups, bolts, nuts, &c.	170,112				
Retaining chains with couplings, bolts, nuts and keys	159,400				
Railing with road bars, spikes, and bolts	180,040				
Total wrought iron	1,698,103	758	1	2	15

	lbs.	Tons.	Cwt.	Qrs.	lbs.
Brought forward		758	1	2	15
CAST IRON.					
Chain saddles with bed plates and rollers	47,480				
Abutment ditto	7,440				
Railing stanchions	61,500				
Cast plates under beams	28,000				
Retaining frames	44,000	84	2	1	8
Total cast iron	188,420				
Total weight of bridge iron-work on Uniform System		842	3	3	23

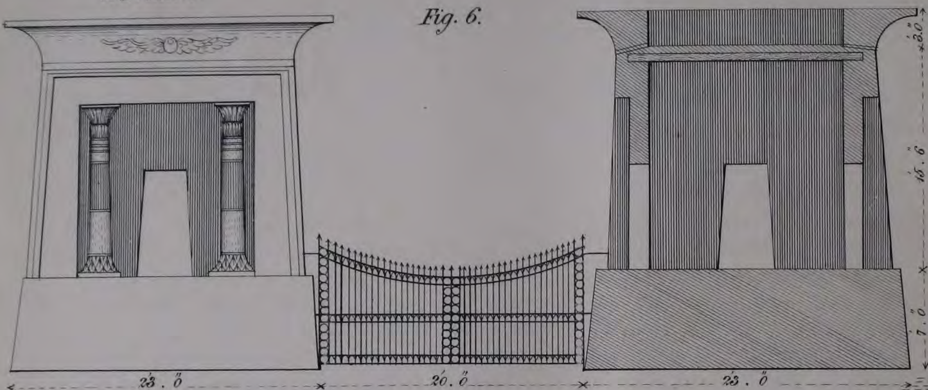
The power of the chains in the calculation of the uniform system has been assumed at 1519 tons, or product of one-half weight into the cosecant of the angle of suspension, and 180 square inches given as the sectional area of the chains. The difference between the weights of the two systems in a bridge of such large dimensions as the one in question, is but 20 tons, 17 cwt., 1 qr., 10 lbs., or about 2½ per cent.,—a trifling consideration with reference to the practical variations of construction, and verifying the demonstrations of the Rev. Mr. Pratt, with whose data this Memoir commenced, and the correctness of which it was intended to illustrate whilst bringing to prominent notice the paramount advantages of the Resultant System.

TOLL HOUSES.

Elevation.

Fig. 6.

Section.



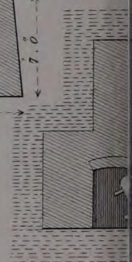
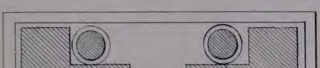


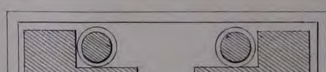
Fig. 7.

Fig. 7.

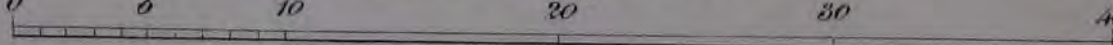


Plan.

Fig. 7.



Scale for Figs. 6 & 7.



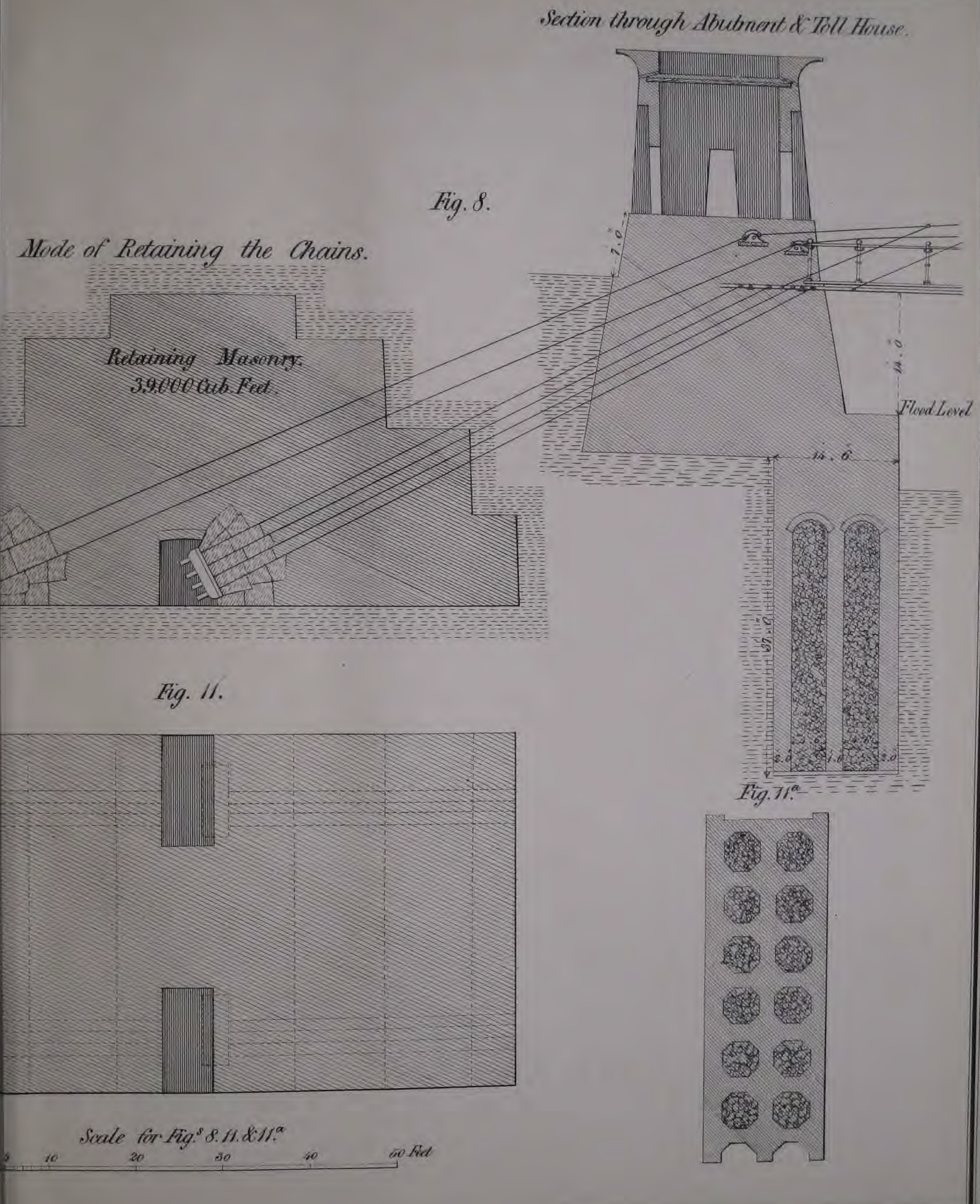


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Fig.

Bird's-Eye View of Half Ch

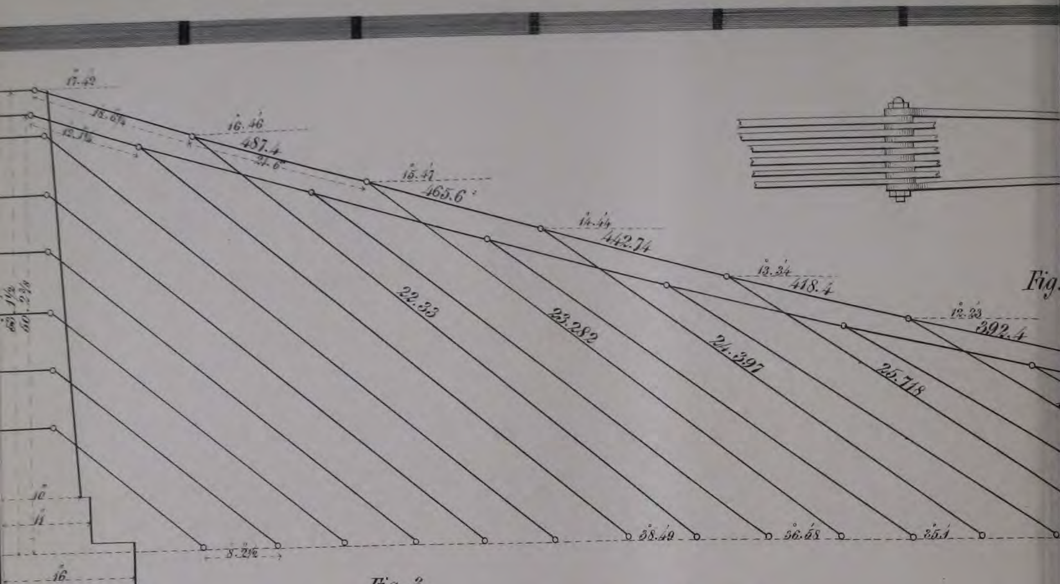
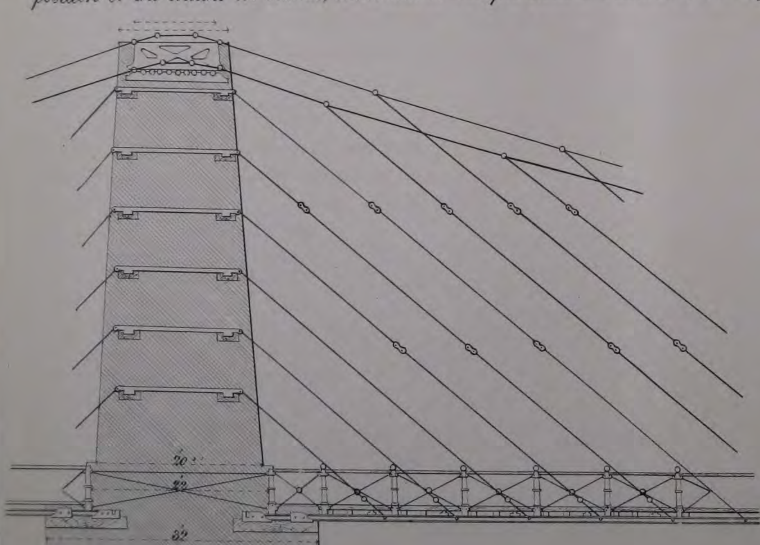
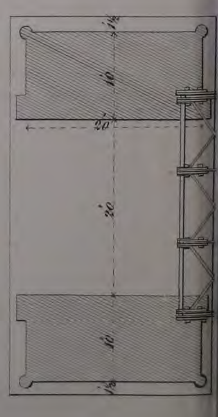


Fig. 3.

Detailed Elevation of a portion of one Curve, shewing attachment of Platform to Pier, position of the Chains on Saddle, connection of Oblique Rods to Standard, Railing, &c.





John Weale, 59,

...n formed of Bars 2×1.

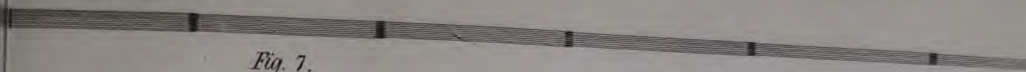


Fig. 7.

Front View of Pr. Oblique Rods and Socket Bolt.

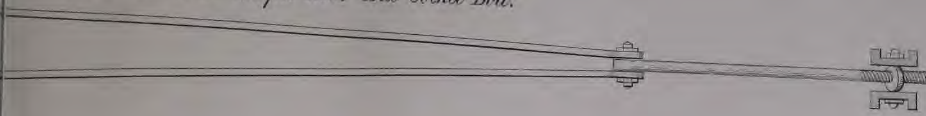
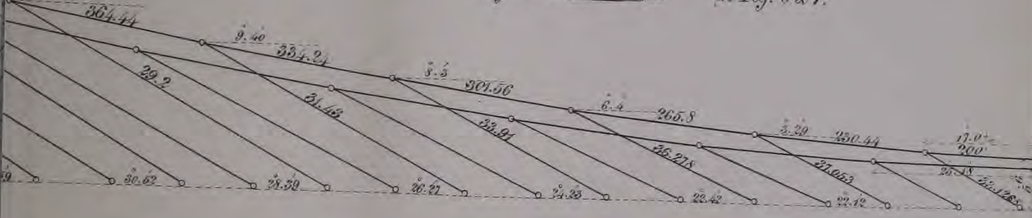


Fig. 8.  Plan & Side View of Socket

Fig. 9.  in Figs. 6 & 7.



Scale for Figs. 6 & 7.

Inches 12 6 0 1 2 3 4 5 Feet

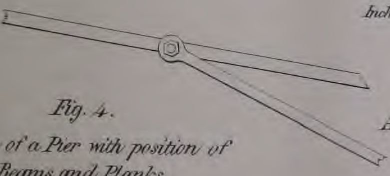
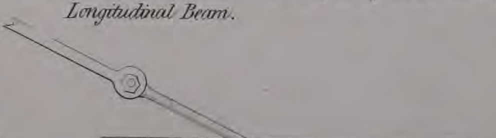


Fig. 4.

Plan of a Pier with position of Beams and Planks.

Fig. 6.

A Pair of Oblique Rods from Chain, showing in Longitudinal Section the attachment by means of self adjusting Socket-Bolt to Longitudinal Beam.



Scale for Figs. 1. 2. 3. & 4.

10 5 0 10 20 30 40 50 Feet

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Fig. 23.

Front View of Pier of oblique Rods at Point of Attachment with Standard.

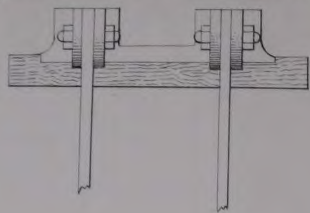


Fig. 5.

Transverse Section of Platform, showing a Trussed T.Beam w

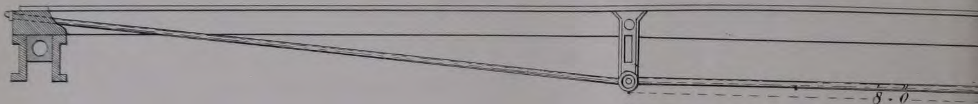


Fig. 11.

Rear View of Cast Box for trussed T.Beam.

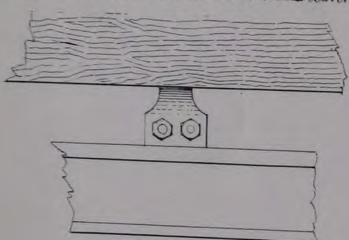
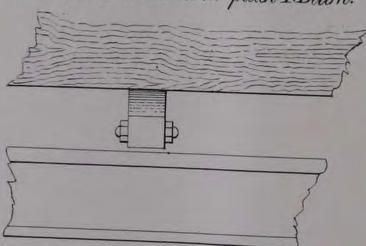


Fig. 12.

Rear View of Cast Box for plain T.Beam.



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Side View of Cas

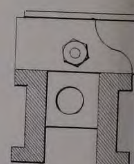
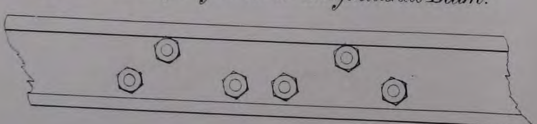
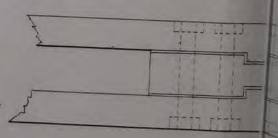


Fig. 17.

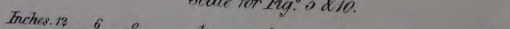
Elevation of Coupling Joint of Longitudinal Beam.

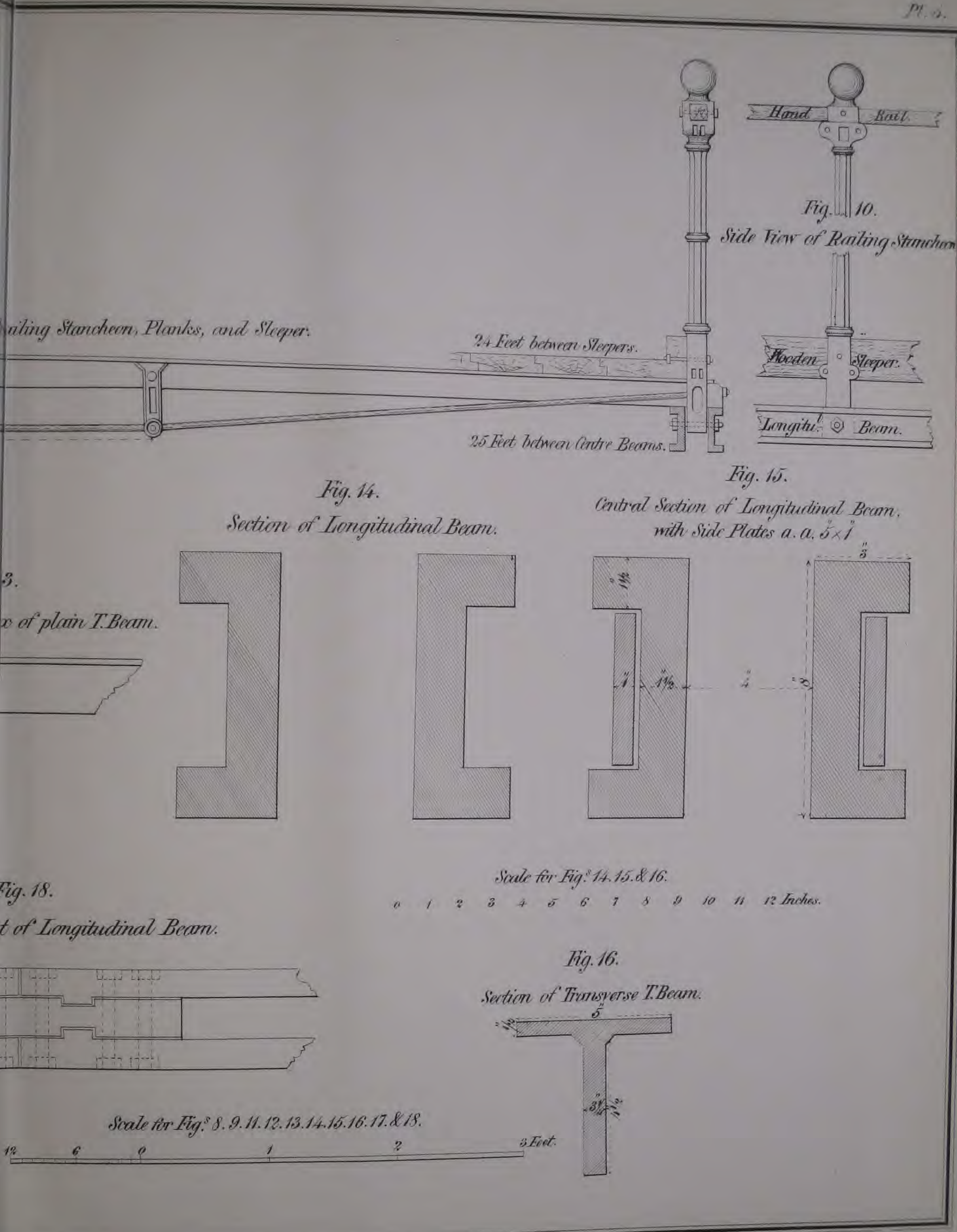


Plan of Coupling Jo



Scale for Fig.s 5 & 10.





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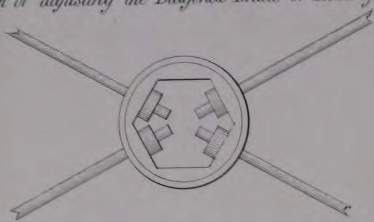
h Holborn. 1849.

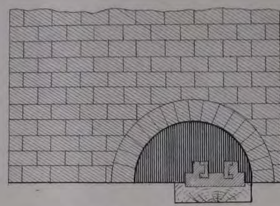
Fig. 25.

Front View of Standard at X. Fig. 4, shewing Arch to be turned over longitudinal Beam during construction to enable adjustment of its length to be made.

Fig. 24.

Plan of adjusting the Diagonal Braces of Railing.





Scale for Fig. 25.

0 5 10 Feet

Fig. 26.

Cast Iron Frames for Retaining Rods for Longitudinal Beam.

Section on C.D.

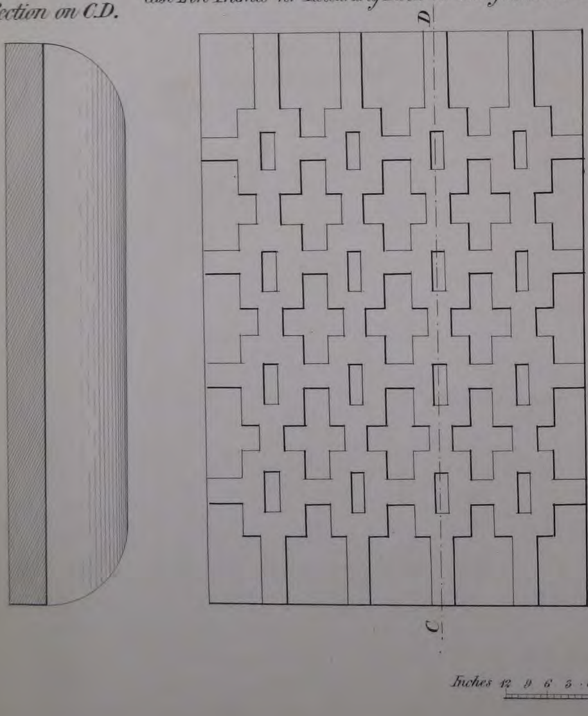
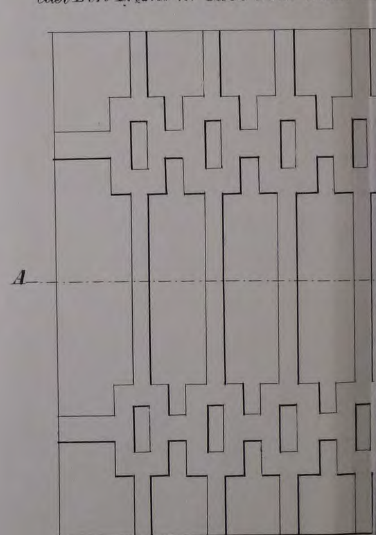


Fig. 27.

Cast Iron Frame for Rods from Chain as



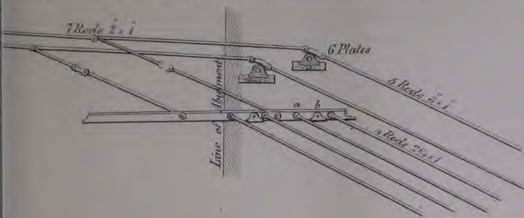
Scale for Figs. 26. 27. & 28.

Inches 12 9 6 3 0 1 2 3 4 5

John Weale, 59, High

Fig. 19.

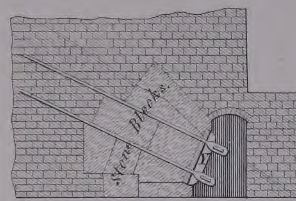
Section shewing Retaining Rods from Chains & Beam.



Scale for Figs 19 & 22.

Fig. 22.

Mode of Retaining Rods in the Cast Frames.



...viewn at Y. Fig. 22.

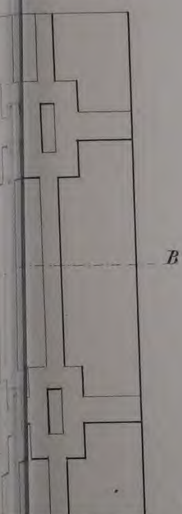


Fig. 20.

Section at a. Fig. 19.

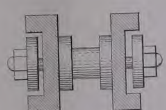


Fig. 21.

Section at b. Fig. 19.

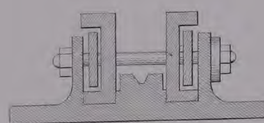
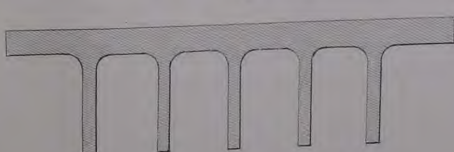
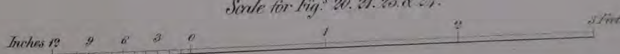


Fig. 28.

Section through A.B.



Scale for Figs 20. 21. 23. & 24.



6 Feet

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...born, 1849.

APPENDIX.

I.

Memoir upon the Quantity of Iron necessary in a Tension Chain Bridge. By the Rev. J. H. PRATT. *Extracted from the 'Journal of the Asiatic Society' in Calcutta, January,* 1848.

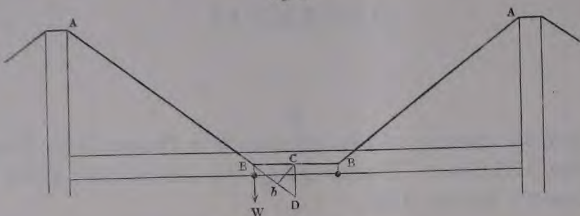
To demonstrate, that the QUANTITY OF IRON *in a suspension bridge, necessary to enable each part to sustain the greatest tension to which it will be subjected when the roadway is loaded to the greatest extent,* IS ALTOGETHER INDEPENDENT *of the* FORM *of the bridge,* HOWEVER COMPLICATED THAT FORM MAY BE, and depends solely upon the width of the bridge, the height of the piers above the roadway, the thickness of the first link in leaving each pier, and the angle that link makes with the horizon.

In the controversy recently mooted in India regarding the superiority or inferiority of taper chains in the construction of suspension bridges, when compared with uniform or common chains, the consideration of the quantity of metal employed is one of considerable practical importance. According to the remarkable property which we have above enunciated, and shall soon proceed to demonstrate, the quantity of iron actually necessary to resist the strains is IN THEORY the same for all forms and positions of chain and suspending rods. But this property points out to us, that in the ACTUAL CONSTRUCTION of bridges the quantity of metal employed will be greater in proportion to the greater variety of strain. For there would always be a practical difficulty in the way of making every portion of iron in a complicated structure *exactly proportional* to the tensions, and no portion must be *thinner*, otherwise the loaded bridge would be in danger of falling, and therefore the probabilities are that many parts would be *thicker* than absolutely necessary. And therefore, as we have said, the economy of iron will be practically greatest in bridges where the varieties of tension are least. This tells, then, in a practical point of view against the taper chain system in the question—taper chain *versus* common chain bridge.

We shall now proceed to the demonstration of the property enunciated, first, however, proving the following lemma which we shall find of use in the course of our investigation.

Suppose, in the first instance, that the bridge is as represented in fig. 1. This is given as a simple case to which we shall refer subsequently as a standard. The roadway is supported by two rods, A B, A B, proceeding from the piers, and attached to the roadway at B and B. The tensions of these rods will not only support the weight of the loaded roadway, but will produce a tension in the line B B, which must be provided

Fig. 1.



for by inserting a rod of iron, B B, of a proper thickness, *i. e.* proportional to this horizontal tension, to prevent the suspending rods from *tearing* the road to pieces. The rods A B, A B must be held down by bolts, as shown in the diagram. Let C be the middle point between B and B: and C b be drawn perpendicular to A B produced.

LEMMA.—*The quantity of iron in* A B *and* B C *necessary to resist the strains is equal to a bar of the thickness at* A, *and of the length* A b.

Draw C D perpendicular to B C and meeting A B produced in D.

The tension of B A at B is balanced by two forces, (1) the tension of B C, and (2) the portion of the weight sustained, acting in B W.

The triangle B C D has its sides parallel to the directions of these forces, and these sides are therefore proportional in magnitude to the three forces.

$$\text{Hence, tension of } BC = \frac{BC}{BD} \times \text{tension of } BA,$$
$$= \frac{Bb}{BC} \times \text{tension of } BA,$$

since the triangle B b C is similar to the triangle B C D.

But the transverse section of iron is to be proportional to the tension. Hence

$$\text{Section of } BC = \frac{Bb}{BC} \times \text{section of } BA;$$
$$\therefore \text{ Quantity of iron in } BC = BC \times \text{section of } BC.$$
$$= Bb \times \text{section of } BA.$$

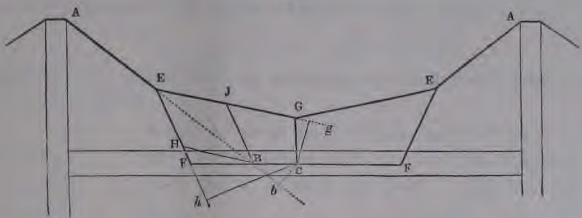
Hence the quantity of iron in A B and B C together = A B × section of A B + B b × section of A B = A b × section of A B = quantity in a bar of length A b, and thickness at A.—Q. E. D.

We shall now proceed to give, first a Geometrical, and then an Analytical, demonstration of the Fundamental Proposition which is the subject of this communication.

1.—GEOMETRICAL DEMONSTRATION.

Let fig. 2 represent the bridge, the dark lines representing the iron-work. The lower parts E B, B C of the rods in fig. 1 are removed, and replaced by E F, F C, and

Fig. 2.



E G, G C, on both sides the bridge: the rod F C is necessary to counteract the horizontal strain of F E, and the rod G C is necessary to hold down E G, E G in position.

We have to show, that if these four new rods are proportional in transverse section to their strains, the quantity of iron in them is the same as in those which they replace, viz. in E B, B C.

Draw C h perpendicular to E F produced, and C g perpendicular to E G produced. Then, by the property already proved in case of fig. 1, the quantity of iron in E F and F C = quantity in a length E h of the same section as E F, and the quantity of iron in E G and $\frac{1}{2}$ G C* = the quantity in a length E g of the same section as E G. Now the tensions of E A, E F, and E G acting at E are in equilibrium. Draw the parallelogram J H. Hence the sides of the triangle B H E (as also of E J B), being parallel to the direction of these three forces, are proportional also to them in magnitude.

$$\text{Hence tension of EF} = \text{tension of EA} \times \frac{\text{EH}}{\text{EB}},$$

$$\therefore \text{section of iron in EF} = \text{section of EA} \times \frac{\text{EH}}{\text{EB}}.$$

$$\text{Also tension of EG} = \text{tension of EA} \times \frac{\text{EJ}}{\text{EB}}.$$

$$\therefore \text{section of iron in EG} = \text{section of EA} \times \frac{\text{EJ}}{\text{EB}}.$$

Hence the quantity of iron in E F, F C, E G, G C = quantity in E h and E g

$$= \text{E}h \times \text{section of EF} + \text{E}g \times \text{section of EG},$$

$$= \text{section of EA} \left\{ \frac{\text{E}h \times \text{EH} + \text{E}g \times \text{EJ}}{\text{EB}} \right\}.$$

But by a property (which we shall prove below, and which we defer at present, in order not to interrupt this demonstration)—

* The other half of G C's substance belongs to the other half of the bridge.

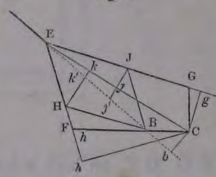
If E H, E J represent the magnitudes and directions of two forces of which the magnitude and direction of the resultant is E B, and from any point C perpendiculars be drawn upon these three directions (produced if necessary), as C h, C g, C b: then E H $\times$ E h + E J $\times$ E g = E B $\times$ E b.

This being assumed, the calculation above gives—

Quantity of iron in E F, F C, E G, G C = E b $\times$ section of E B = quantity of iron in E B and B C.—Q. E. D.

We shall now demonstrate the property we have just assumed.

Fig. 3.



The lines in fig. 3 are the same as in fig. 2, except that in addition H k, J j, are drawn at right angles to E C and meeting E B in k' and j'. Now the triangles E H k, E C h are similar;

$$\therefore \text{EH} : \text{E}k :: \text{EC} : \text{E}h;$$
$$\therefore \text{EH} \times \text{E}h = \text{EC} \times \text{E}k.$$

So also from the similar triangles E k k', E b C we have

$$\text{E}k : \text{E}k' :: \text{E}b : \text{EC};$$
$$\therefore \text{EC} \times \text{E}k = \text{E}b \times \text{E}k'.$$
$$\text{Hence EH} \times \text{E}h = \text{E}b \times \text{E}k'.$$

In precisely the same manner

$$\text{EJ} \times \text{E}g = \text{E}b \times \text{E}j'.$$

Now in the triangles E H k', B J j' the angles are equal, and E H = B J: hence the triangles are equal, and $\therefore$ E k' = B j';

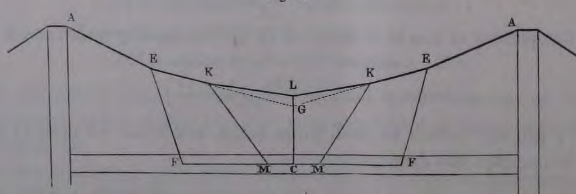
$$\therefore \text{E}k' + \text{E}j' = \text{B}j' + \text{E}j' = \text{BE}.$$

Hence, then, from the above

$$\text{EH} \times \text{E}h + \text{EJ} \times \text{E}g = \text{EB} \times \text{E}b.\text{—Q. E. D.}$$

We have thus proved the proposition, which we began by enunciating, in the case represented in fig. 2. But the same is true in any other case. For (see fig. 4) we may

Fig. 4.



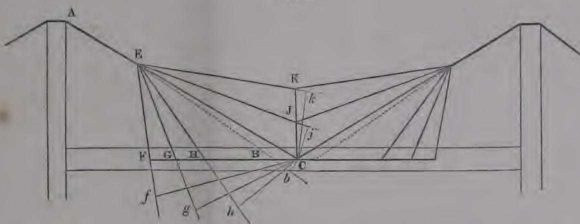
suppose the rods K G, G C taken away, and others K M, M C, K L, L C put in their place, and the reasoning will be precisely the same, and the result the same, however many subdivisions be made. And therefore the property is universally true.

The above demonstration is GEOMETRICAL only; but by the help of analysis we may give the following proof, which at once applies to every case which can occur.

II.—ANALYTICAL DEMONSTRATION.

Suppose E B, B C removed, and replaced by any number of rods E F, F C; E G, G C; E H, H C; E J, J C; E K, K C, &c.

Fig. 5.



Let θ_1 θ_2 θ_3 . . . . be the angles which E F, E G, E H make with A B.
θ'_1 θ'_2 θ'_3 . . . . E J, E K, ...
Let S be the transverse section of iron in A B :
S_1 S_2 S_3 . . . ditto . . in E F, E G, E H, ...
S_1' S_2' S_3' . . . ditto . . in E J, E K, ...

Then, by hypothesis, S S_1 S_2 S_3 . . . . S_1' S_2' S_3', are proportional to the tensions of those rods.

Draw C f, C g, C h, C b, C j, C k, . . perpendicular to E F, E G, E H, E B, E J, E K, ... Join E C. Let E C $= a$; and B E C $= d$.

Now because the tensions at E are in equilibrium;

$$\therefore S = S_1 \cos. \theta_1 + S_2 \cos. \theta_2 + \ldots + S_1' \cos. \theta_1' + S_2' \cos. \theta_2' + \ldots$$
$$o = S_1 \sin. \theta_1 + S_2 \sin. \theta_2 + \ldots + S_1' \sin. \theta_1' - S_2' \sin. \theta_2' - \ldots$$

Then multiplying the first of these by a cos. d and the second by a sin. d and subtracting.

$$S. a \cos. d = S_1 a \cos. (\theta_1 + d) + S_2 a \cos. (\theta_2 + d) + \ldots$$
$$+ S_1' a \cos. (\theta_1' - d) + S_2' a \cos. (\theta_2' - d) + \ldots$$
$$\text{or } S \times Eb = S_1 \times Ef + S_2 \times Eg + \ldots + S_1' \times Ej + S_2' \times Ek + \ldots$$

or quantity of iron in E B, B C = quantity in E F, F C; E G, G C, &c.—Q. E. D.

If any of these bars be similarly subdivided, the same is true; and the most complicated system we chose may thus be devised; but the same result is true.

N. B. The effect of the *weight* of the rods themselves has been neglected in these calculations, because it is always so small a quantity compared with the tension. A bar of iron one square inch section will support 9 tons without stretching: the *weight* of one foot of such a bar is only 3·31 lbs., which equals ·00148 of a ton, or ·00016 of 9 tons, a fraction so small that it may be omitted. But the proposition is nevertheless rigidly true, even when the weight of the rods is taken into account.

II.

Return of Properties in Cultivation at St. Lucia, indicated by Numbers on the Map prefixed.

No.	Names of Estates.	Names of Proprietors.	Moving Power of Mill.	No. of Acres in Cultivation.
1	Union	Hon. M. G. Todd . . .	Steam.	90
2	Choc	Auxliens Augier	Do.	95
3	Vide-Bouteille . .	Do.	Water.	36
4	Entrepôt	Denis Bonnet	Steam.	30
5	Incommode . . .	William Muter	Do.	65
6	Soucis	Do.	Do.	60
7	La Pointe . . .	François Garnier . . .	Do.	50
8	Marigot	Blasse	Cattle.	25
9	Perle	William Muter	Steam.	76
10	Pérou	Do.	Do.	55
11	Mont d'Or . . .	Do.	Water.	58
12	Roseau	Do.	Steam.	142
13	Mont Plaisant . .	Gabriel Leuger	Water.	40
14	Anse Galet . . .	Do.	Do.	35
15, 16	Deux Amis . . .	William Muter	Do.	52
17	Anse Mahaut . .	Charles Allery	Do.	30
18	Anse Mamin . .	Veuve d'Yvoly	Do.	40
19	Palmiste	Guy de Mareuil	Do.	70
20	Réunion	Bellile Duboulay . . .	Do.	36
21	Rubis	Do.	Do.	38
22	Perle	Marryat and Co. . . .	Do.	60
23	Diamant	William Muter	Do.	41
24	Soufrière . . .	Dame Daniel Gordon . .	Do.	60
25	Morne Courbaril .	Desrivières Deveau . . .	Do.	55
26	Malgré Tout . .	Chas. de Laubenque . .	Do.	52
27	Rabot	William Muter	Do.	18
28	Belle Vue . . .	Auguste Cuvillier . . .	Cattle.	33
29	Belle Plaine . . .	La Veuve Henry King . .	Do.	27
30	Imbert	Louis Grancour	Do.	26
31	Dauphine . . .	Louis Duboulay	Do.	24
32	Fond-doux . . .	Henri Glace	Do.	30
33	Pitons	Lecurieux Chalon . . .	Water.	62
34	Beau Séjour . .	Chas. de Laubenque . .	Do.	33
35	Espérance . . .	Rosemond et Parigaux .	Do.	35
36	Château Belair . .	Lecurieux Chalon . . .	Do.	45
37	Union Vale . . .	Hon. J. Goodman . . .	Do.	80
38	Anse Ivrogne . .	Clairet	Do.	14
39	Delser	Lecurieux Chalon . . .	Do.	60
40	Réunion	Beausoliel, Jo. Jh. . . .	Do.	42
41	Rivière Dorée . .	Dames Alexander . . .	Do.	52
42	Desgatières . . .	Do.	Do.	50
43	Mont Lézard . .	Auxliens Augier . . .	Do.	37
44	Parc	Do.	Do.	67
45	Beau Séjour . . .	Numa Chauton	Do.	45
46	Balambouche . .	Gaillard de Laubenque . .	Do.	120
47	Saphir	Dames Rouvier	Do.	82
48	Black Bay . . .	John Goodman	Do.	75
49	Anse Noir . . .	E. Cotter	Cattle.	65
50	Tourny	St. Romain Laporte . .	Wind.	85

No.	Names of Estates.	Names of Proprietors.	Moving Power of Mill.	No. of Acres in Cultivation.
51	Ressource . . .	Auxliens Augier . . .	Wind.	42
52	Retraite	Goodman and Marucheau .	Water.	70
53	Beau Séjour . .	The Heirs of Moreau . .	Do.	40
54	Beau Séjour . .	Dame Guery	Do.	38
55	Mon Repos . . .	Amable Dreuil	Wind.	52
56	Pointe Sable . .	D. Minvielle	Do.	75
57	Belle Vue . . .	Veuve Cotter	Do.	55
58	Savanne	M. Beausoleil	Water.	47
59	Cannelles . . .	William Muter	Do.	105
60	Fond Cajou . . .	Xavier Pinel	Cattle.	20
61	Beauchamp . . .	McCombie	Water.	68
62	Troumassé . . .	William Muter	Do.	60
63	Mon Désir . . .	St. B. de Brossard . . .	Do.	44
64	Volet	William Muter	Do.	26
65	Fond Lauréol . .	Goodman and G. Cotter .	Do.	82
66	Orangerie . . .	John Richardson . . .	Do.	24
67	Praslin	Cavan and Co.	Do.	28
68	Anse Canot . . .	Beaucé	Do.	95
69	Fond d'Or . . .	Marryat and Co. . . .	Steam.	115
70	La Caie	Cavan and Co.	Cattle.	31
71	Richefond . . .	Do.	Water.	105
72	Grande Anse . .	D. Ferguson	Steam.	70
73	Marquis	Heirs of Laurence . . .	Water.	130
74	Espérance . . .	Chas. de Brettes . . .	Cattle.	40
75	Cap	Do.	Steam.	55
76	Belle Vue . . .	Mad. Ste Catherine Jore .	Cattle.	38
77	Beau Séjour . . .	Prudent Dorcilly . . .	Do.	24
78	Bonne Terre . .	William Muter	Steam.	50
79	Réduit	Heirs of Acquart . . .	Do.	80
80	Bois d'Orange . .	William Muter	Do.	80
81	Corinthe	B. La Corbinière . . .	Water.	60

A True Copy. (Signed) W. Reid,
Lieut.-Colonel, Royal Engineers.

END OF VOL. X.

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