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PAPERS

ON SUBJECTS CONNECTED WITH

THE DUTIES

OF THE

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PREFACE.

The Editor much regrets that, owing to Lieut. Colonel Home's state of health since his return from Ashantee, the present volume contains no account of the Engineering operations of the Expedition. The Shoeburyness experiments, since the publication of the last volume, have not been of sufficient interest to require recording in the present one.

C. S. HUTCHINSON,
Lieut. Col., Royal Engineers,
Editor.

Railway Department,
Board of Trade, Whitehall,
September, 1874.

LIST OF PLATES.

ERRATUM IN VOL. XXI.

Page 90, line 19, for "80 ft." read "180 ft."

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MEMOIR OF
MAJOR GENERAL SIR HENRY MARION DURAND, K.C.S.I., C.B., R.E.

By LIEUTENANT G. T. PLUNKETT, R.E.

The following sketch of the career of the late ruler of the Punjab should properly have appeared in the same volume with the memoirs of Sir J. F. Burgoyne and Sir W. Denison, but it is only since the publication of that volume that the writer has been enabled to gather from the notices which appeared in various Indian newspapers at the time of his appointment to govern that Province, and again after his death, the principal incidents of his life, and to supplement these by further information which has lately been very kindly placed at his disposal.

Public opinion, both in India and at home, did full justice to Sir Henry Durand's merits during the last few years of his life, when he was universally acknowledged to be one of the most able men whom the Indian Engineers have produced, and it seems fitting, when we lose so gallant a soldier, so accomplished a scholar, and so upright a statesman, that an outline of his life and services should be recorded in these pages, as a memorial of his connexion with the Corps, and an encouragement to others to tread in his footsteps.

Henry Marion Durand was born on the 15th of November, 1812, and on obtaining a cadetship at Addiscombe, was a contemporary of the present Commander-in-Chief in India, Lord Napier of Magdala; a fight between the two boys was remembered and afterwards mentioned by Durand, who was worsted in the encounter, but it appears to have been forgotten by the victor; it is also said that, on account of his small size, his brother cadets objected to his obtaining a corporal's stripes; but he must have grown afterwards, as he was by no means short when he came to India.

In 1828 (his first commission being dated 12th of June in that year) Durand left Addiscombe for the Royal Engineer Establishment, at Chatham, and on completing his studies there, Sir Charles Pasley wrote of him in the following terms to Lord Fitzroy Somerset :—

My dear Lord Fitzroy,

I received your note respecting Mr. Durand, an East India Engineer Cadet, who has just quitted me, having completed the usual course ; he was one of a party of seven who joined at the same time ; by superior diligence he finished before the others, and he is one of the most distinguished young Engineers whom I have ever had under me, both in respect to diligence, ability, and conduct. He was in all my monthly reports of progress, &c., returned exemplary as to conduct, and generally *extremely diligent* or very diligent, not merely in *quantity* but in *quality* of work performed, all his drawings and exercises being finished in a creditable manner. I never had occasion to find fault with him.

If your Lordship can procure or give him any recommendation to the authorities in India, you will not only serve a young man of great merit, but do good to the service there, by bringing forward a young officer whose principles, I believe, are equally good with his abilities. I myself take a great interest in him, though I know nothing of his family.

I remain, &c., &c.,

(Signed) C. W. PASLEY.

Durand in due course embarked for India, but the vessel in which he sailed was wrecked near the Cape, and the passengers were taken on by another vessel, which reached the shores of India in May, 1830. No sooner did they enter the Hooghly, than Durand, whose impatience could not brook the tedious passage up its tortuous channel, which, even since the invention of steam tugs, is difficult and sometimes dangerous, pushed on to Calcutta in an open boat, and thus escaped a second shipwreck which befel the other passengers. He landed, however, in Calcutta destitute of baggage, and had to borrow from the wardrobe of Bishop Turner, in whose palace he stayed, the clerical style of the garments procuring him the appellation of the " Chota Padre Sahib" or " Junior Clergyman." These incidents show how great was the difference between a voyage to India in 1830, and the journey as now performed by the overland route.

On being sent up country, his first work was in the formation of the hill station at Landour, and being directed to survey and report upon suitable sites for other sanitaria, he brought to notice the advantages possessed by Châkrata. More than thirty years afterwards he saw his views adopted, and as Military Member of Council, had to examine the project for establishing there a cantonment for English troops. We next find him employed on the works at the head of the Jumna Canal, under the orders of Captain (afterwards Sir Probyn) Cautley, and in company with Lieutenants Napier and Baker (now Sir W. Baker). Whilst exploring the lower range of the Himalayas called the Sewaliks, Dr. Falconer and Lieut. Cautley had discovered in large quantities fossils which they at once recognized as of great value to the geologist. In the fourth volume of the "Journal of the Asiatic Society of Bengal," published in 1835, Major Colvin states that he has ordered a regular search to be instituted, and there are descriptions by Baker of the fossil elk; one of these is prefaced by a notice of the discovery of the remains of the hippopotamus, written by Durand. Of these relics, large drawings were made by the latter officer, and these afterwards appeared in the Asiatic Society's researches. The next volume contains Captain Cautley and Dr. Falconer's description of the Sivatherium, and a series of meteorological observations made by the engineers, with notes by Durand, who also contributes to this number four papers on the remains of the rhinoceros, carnivora, fossil pig, and quadrumana, the latter including an ape of immense size. The English and French savants made light of this latter discovery, but more than thirty years afterwards Professor Owen enquired where the notice of it was to be found, and whither the fossil had been sent, as Du Chaillu had brought to light the gorilla, whose dimensions were on a similar scale. Many of the plates by which these articles are illustrated were etched on the spot by Lieut. Durand, and transmitted by him to Calcutta, to be printed from.

The engineers had other work to do besides investigating interesting geological questions, their professional duties being sufficient to occupy the attention of less zealous enquirers after knowledge; but this did not prevent Durand from making the most of the opportunity afforded him of becoming thoroughly acquainted with the land revenue system of India. An officer employed in the Irrigation Department is constantly brought into contact with the agricultural classes, and has peculiar facilities for acquiring a knowledge of the real condition and wants of the people, and he made the best possible use of these advantages. He also at this time became acquainted with two men of marked ability in the Indian Civil Service, Thomason and Colvin, who were subsequently secretaries to Lord Auckland, and afterwards in succession Lieut. Governors of Agra.

After five years spent in the Canal Department, Lieut. Durand was offered the post of secretary to the Agra Board of Revenue, an uncommon tribute to the talents, industry, and powers of observation of a young military officer. This appointment he accepted and was about to take up, when preparations were commenced for the march of an army into Affghanistan, in order to reseat Shah Soojah on the throne. He at once begged to be allowed to resign the secretaryship and join the expedition, and having with some difficulty obtained permission, he proceeded to Delhi to prepare the engineer park, and was appointed topographical surveyor to the army of the Indus.

He accompanied Sir Willoughby Cotton's column to Kandahar, being employed on the march, with other engineers, in the operation of bridging the river Indus. From Kandahar, the army united under the command of Sir John Keane, advanced upon Ghuznee, which was the strongest place in Affghanistan, and considered by the inhabitants of the country to be impregnable; but Major Todd, of the Bengal Artillery, and Lieut. Leech, of the Engineers, who had seen the fortress, had reported that it was of no great strength. Sir John Keane, who had with great difficulty brought a siege train through the Bolan Pass to Kandahar, left it there, and consequently found himself before the citadel of Ghuznee, of great natural strength, and fortified with the utmost skill and care of which the defenders were capable, without any means of effecting a breach in its walls. Major Thomson, the chief engineer, suggested that a gate should be blown in by a bag of powder, and a deserter from the garrison gave information that one gate only, that on the Kabul side, had not been built up with masonry. On the night of the 22nd of June, the storming parties were assembled, and soon after midnight the field artillery opened fire upon the ramparts, to draw off the attention of the besieged, while at the same time Major Thomson, with Lieutenants Durand and Macleod, and Captain Peat, of the

Bombay Engineers, piled the powder bags at the Kabul gate. The hose was attached, but would not at first ignite, and Durand had to scrape the end with his nails before he succeeded in setting light to it. The explosion was completely successful, and nothing remained of the gate but a heap of ruins. Col. Dennie, of the 13th Light Infantry, rushed in with the stormers, and drove back the enemy, who came down to defend the breach. Brigadier Sale followed with the main column, but found Captain Peat, who, having been thrown down by the explosion, and lying shattered and bewildered on the ground, told the Brigadier that the gate was choked with rubbish, and that the stormers could not get in. The retreat was sounded, and the column halted; but fortunately Durand had ascertained the true state of affairs, and reported Colonel Dennie's success. The column again advanced, and the British colours were soon planted on the citadel of Ghuznee. The good service rendered on this occasion by the engineers was fully appreciated, for a check before Ghuznee would have seriously endangered the safety of the entire force, which could obtain neither provisions for a protracted stay in that part of the country, nor means of transport sufficient for its return. Abundance of supplies was found stored in the fortress, and the army continued its march to Kabul, before which it arrived on the 6th of August, 1839. In September it was decided that a great portion of the force should remain in the country for the winter, and it became necessary immediately to decide where the brigade ordered to occupy the capital should be housed. Lieut. Durand, who had been appointed engineer to the Shah's army, was called to the council assembled to consider this important question, and at once showed that the only fit position for the location of our forces was the Bala Hissa, a strong place containing good shelter for the troops, and a citadel which commanded the city. The political officer, however, Sir William Macnaghten, neglected to make adequate preparations, and weakly listened to the objections of the Shah, who was opposed to the occupation of this fortress by the British. Some barracks were commenced but afterwards given up, and only a few troops temporarily lodged in buildings at the foot of the citadel. Disgusted with the want of common sense and firmness displayed by those on whom the success of the enterprise depended, Durand obtained permission to return to India with Sir John Keane's column, which marched from Kabul on the 15th of October. He was afterwards employed in completing his reports and arranging the results of the surveys he had made, and before the end of 1840 he went to England on furlough.

The insurrection of the Affghans commenced in November, 1841. Some officers, especially Lieut. Sturt, of the Engineers, who had succeeded Durand, again urged that their position in cantonments was untenable, and that in spite of the want of preparations in the Bala Hissar, its occupation would still save the army; but this advice was not taken—the opportunity was lost, and little hope remained for the lives or honour of the English, who soon after perished miserably in the attempt to escape through the passes.

Afterwards, in 1850, Durand published in the *Calcutta Review*, a clear account of "The Outbreak in Kabul, and its causes;" the latter he showed to be, in the first place, the jealousy of military authority and the monopolizing of all power by the Civil Service of India, so that, in all expeditions, the military commander was controlled by a political officer, responsible, not to the Commander-in-Chief, but to the Governor General, through his secretaries. The result of this divided responsibility was, that, trusting to the diplomatic arrangements and imaginary foresight of the "Politicals," the Military Authorities omitted to take proper precautions for the safety of the forces under their orders; they were kept in perfect ignorance of much that was going on around them, and then Durand remarks, "No sane person can expect the Military Chief to take up the game and play it well at a moment's notice, and without a pause, from the hands of one who has thoroughly embroiled it." Nowhere has the folly of this division of authority, and the fatal consequences which must be expected from it, been more plainly set forth than in this article. Ten months after Durand's arrival in England, Lord Ellenborough, who had been appointed to succeed Lord Auckland as Governor General, asked Durand to accompany him as Aide-de-camp, and, on landing in Calcutta, made him his private secretary, and there can be no doubt that his opinion had great weight with the Governor General, who strongly opposed the old clique of the Indian Civil Service, which, composed almost entirely of the relatives of the directors, monopolized nearly every post of honour and emolument in the country. The private secretary was with Lord Ellenborough at the battle of Maharajpoor, and took advantage of this visit to Central India to obtain a thorough knowledge of its condition and its politics; on the 12th of January, 1843, he became a Captain, and on the 28th March following, married, at Meerut, the third daughter of Major General Sir John McCaskill, K.C.B., who was afterwards killed at the battle of Moodkee.

Captain Durand's next appointment was to succeed Major Broadfoot, of the Engineers as Commissioner of the Tenasserim Provinces; here he set to work with his usual energy, and the good which he accomplished during his tenure of office was afterwards generally acknowledged; many of his acts, however, prompted by admiration of, and sympathy with, the small party of self-denying American Missionaries who were labouring in the midst of many difficulties for the conversion of the Burmese, excited fierce opposition; and there were not wanting men among the Governor General's advisers who were ready to judge harshly any line of policy inaugurated by the rising military-civilian. While he was in Burmah the first Sikh War was fought, and he paid a visit to Calcutta to volunteer for active service; his offer, however, was not accepted, and he returned to Burmah, where he is considered to have laid the foundation of the non-regulation, or, as it might have been called, patriarchal, system of government which was in late years so successfully introduced into the Punjab and other Provinces. Recalled, owing to the opposition above referred to, from Burmah, Captain Durand was appointed by Lord Hardinge to officiate as chief engineer of the Punjab, but soon after obtained leave to England, and on his return at the time of the second Sikh war, took part, with other engineers, in the campaign of Chillianwallah and Goojerat. A very able critique on the strategy displayed and the mistakes made in the conduct of these operations, was subsequently written by Durand, and appeared in the *Calcutta Review* in 1851. In this he shows the inadequacy of our artillery, and points out that as there was little doubt of our having some day to fight a second war in the Punjab, we should have prepared for it by employing a few engineers to survey and reconnoitre the country beforehand. He also calls attention to a repetition of one of the errors of the Affghan war, in dividing the political from the military authority, instead of entrusting the conduct of the whole to one leader.

At the close of this war he became political resident at Sindhia's court at Gwalior, and afterwards occupied similar positions at Bhopal and Nagpore, having qualified himself especially for such posts by previous careful observation of Central Indian politics. During the period from 1850 to 1854, he published in the *Calcutta Review* a series of articles on Indian topics. In these he enlarges upon the indifference of the English to the welfare of their Indian empire, deplores the ruin which in many places our rule has brought upon the native gentry, and protests against the folly of looking upon a few English-speaking Bengalies as representing the vast populations of the many countries directly or indirectly under our rule. In many points, his criticisms and suggestions for reform agree closely with those lately put forward by Col. Chesney, R.E., in his Indian polity. He strongly urged the necessity for a searching enquiry, by impartial members of the imperial legislature, into the whole question of the manner in which the East India Company had fulfilled its duties. He also wrote an account of the causes which led to the second Burmese war, and the operations by which it was brought to a successful termination; and in another article is presented a vivid picture of the obstacles and hardships encountered by the devoted missionary Adoniram Judson, the "Apostle of Burmah," who had sacrificed his health and his life to promote the advancement of the cause for which he had so long and earnestly worked.

In 1853 Lieut. Colonel Durand took leave to England, and on his return in 1856, entered upon the appointment of Superintending Engineer in the P. W.D. at Calcutta. Early in 1857 he was sent as political resident to Indore. In May, 1857, news was received of the mutiny of the native troops in most of our principal stations, and it was evident that those of the contingent at Indore were ready to follow their example. Durand, however, took care not to show any distrust in the men, and informed Holkar that he would be held responsible for their loyalty; at the same time he requested that two guns, two troops, and two companies of the Bhopal contingent, who evinced a better spirit, should be sent to him from Sehore. They marched on the 16th, and a fortnight later another troop and a company of infantry followed. The European residents were directed to assemble at the Residency, and the best possible arrangements were made to secure for all a safe retreat in case of an outbreak. On the 1st of July the Indore troops mutinied, and the regiments who should have defended the Residency made a sudden attack upon it. Lieut. Colonel Travers, who commanded, got the two guns of the Bhopal contingent into position, and ordered the cavalry to charge the enemy's artillery, but only five men followed their officer. The artillerymen alone, under two English sergeants, behaved splendidly, and kept the mutineers at a distance, while Colonel Durand and Captain Magniac did their utmost to assist Colonel Travers in keeping the Bhopal cavalry and infantry firm. Their efforts were unsuccessful, as none but the gunners would fight; so yoking the bullocks to the guns, and mounting on the limbers and waggons such of the women and children as were unable to walk, they commenced, under a fire of grape and round shot, a retreat towards Mundlaisir, where, by Durand's foresight, a fort had been provisioned and made defensible. The troops, however, when they had got ten or twelve miles from Indore, insisted on marching to Sehore, as they feared that their families who lived there, would not be safe. The route had to be changed accordingly, and pushing on as rapidly as possible, with hardly any rest until ten o'clock the following night, a halt was then made in a jungle, where water was obtained. The next morning, on coming to a river on the borders of the Bhopal territory, an armed force was seen drawn up on the opposite bank, as if to dispute the passage; it, how-however, turned out to be a guard sent by the Begum to escort the British to a place of safety. During all this trying march, the courage and presence of mind displayed by Mrs. Durand were invaluable in keeping up the spirits of the fugitives, and extorted the highest admiration from the officers of the force. In August she died at Mhow, from the effects of the fatigue and hardships she had undergone.

Durand having met the small force advancing under Brigadier General Stuart, returned with them to Mhow, where, during the rains, they, perforce, remained inactive. In the meantime the insurrection spread rapidly over Central India, till the forts of Neemuch and Saugor and the cantonment of Nagode (where the 50th N.I. stood firm) were the only places between Agra and the Nerbudda where the British colours still waved, with the exception of Mhow, where Stuart's very weak column, confronted by a powerful enemy at Indore, was preparing to assume the offensive. The rains of 1857 lasted longer than usual, but at length the tracks across the soft black soil, which in that part serve as roads, began to dry; and at the same time the mutineers of Dhar and Amjherra, by attacking stations on and near the Bombay road, threatened to cut off Mhow from all communication with the south. The force available was as follows:—

To march into the field—206 H.M.'s 14th Light Dragoons, 139 Artillery with 9 guns, 173 H.M.'s 86th Regiment; total, 518 Europeans, and of different native corps, 883; making in all 1,401.

In addition to these, 89 Europeans and 144 Natives were left to hold the fort of Mhow, which Durand had done his utmost to strengthen, at the same time urging upon the Government that all such forts should be so constructed as to be capable of defence by a few heavy guns and a small number of European infantry and artillery.

The actual command of the force which took the field was vested in Brigadier Stuart, but Durand, as agent to the Governor General for Central India, had the general direction of the campaign; and in both the conception and the execution of the operations which were carried out, it is impossible to overlook the thorough knowledge of strategy which was displayed. As soon as they found their communications seriously threatened, they took the field against the Dhar rebels, and on the 22nd found them drawn up for action outside the town, where they could derive assistance from the guns of the fort. The enemy was attacked and defeated; some of his troops dispersed, and others took refuge in the fort, of which the siege was immediately commenced. The British batteries and infantry occupied a narrow ridge, with the town and its disaffected inhabitants and mutinous troops in their rear; so close, indeed, was the town, that the Brigadier was shot at from this side during the siege. In front was the fort wall. On the 25th and 26th, the fort was bombarded, but the garrison were well covered, and shewed no signs of yielding, so on the 28th a breaching battery was established, and by the evening of the 31st a breach was made, which, though difficult and well flanked, was practicable. The garrison, however, shrank from its defence, and escaped by night through the weak lines of the besiegers, leaving behind several guns and above eighty thousand pounds as prize to the victors. From this place the column marched northwards, where a rebel leader had collected round Neemuch and Mundesoor 15,000 to 20,000 men and 24 or 25 guns, and, after a fight with some cavalry at Rawul, near Michielpoor, arrived on the 21st on a ridge four miles south of Mundesoor, where it was attacked by the enemy, whose troops were repulsed and driven into the town. The next day the British force forded the river above the town (after again defeating the enemy's horse) to intercept the force which had been besieging Neemuch, and which now, having raised the siege, was hastening to effect a junction with that in Mundesoor. About 700 had joined the 23rd, when a second battle was fought close to the town; the hostile army was well posted, but it was first shaken by a well-directed Artillery fire, and then the British line, attacking in echellon from the right, threw back the enemy in confusion upon his centre and right. At this period a vigorous sally was made from the town by a force 1,500 or 2,000 strong upon the rear of the British, but this attempt had been already foreseen and guarded against, and the enemy was driven in confusion from the field with the loss of his Artillery; so weak, however, was our side in Infantry, that a party who had taken refuge in a strong village, and who defended themselves with desperation, were not dislodged for two days. In this brilliant action, in which 1,400 men (of whom only 500 were English) completely defeated 7,000, our loss was one officer killed and three wounded, and 50 or 60 men killed and wounded, while on the other side nearly 1,000 were killed and many more wounded. The column then marched southwards, taking the road by Bojein that it might be ready either to march upon the Nana and Tantia Topee, had they advanced with the Gwalior and Banda men southwards, or to march upon Mhow and Indore as they did, arriving on the 15th of December, when, though the reinforcements which he had been looking for from the south had not arrived, Durand called upon Holkar's regiments to lay down their arms. The whole of the troops (including the two regiments which had taken part in the attack on the residency) quietly submitted, and the next day Durand handed over charge to Sir R. Hamilton, during whose absence in England he had held political charge of Central India. Leaving Mhow on the 21st of December, he proceeded to Bombay, and thence by sea to Calcutta to join the Governor-General, with whom he was for some time employed on special duty.

From 1858 to 1861, Colonel Durand was a member of the Council of the Secretary of State at home, and in the discussions on the scheme proposed, and in the end adopted, for the amalgamation of the Indian with the imperial forces, he strongly opposed the measure, which he did not consider calculated to increase the efficiency of the Indian services. He then sailed, at the request of Lord Canning, to take the post of Foreign Secretary, for which his experience in Central India and other dependent states, as well as his great influence with the native princes, had eminently qualified him. In 1863 he became military member of the council of the Viceroy, and had served in this capacity nearly seven years, when Lord Mayo saw that the gallant veteran was, above all others, the best fitted to rule the great frontier state, filled with a warlike population, which bars the entrance to Hindoostan. At a public dinner after the great Durbar at Lahore, the Governor General said that Major General Sir Henry Durand had been chosen to succeed Sir Donald Macleod as Lieut. Governor of the Punjab, and the announcement was received with enthusiastic applause. Lord Mayo said, "In Major General Sir H. Durand you will find a Lieutenant Governor worthy to be the successor of Sir Donald Macleod; you will have one of the foremost men in the Indian service; you will find in him all those great qualities which enable men to rule with success; you will find him firm and fearless, honest and brave . . . he has ability enough to enable him to fill with distinction the highest positions in the public service." No higher praise could be given to any man than such an expression of opinion from a statesman who was particularly distinguished by his power of discriminating character. He closed his address with a few words, which all men who serve in India, whether soldiers or civilians, should lay to heart: "I would ask you especially to avoid provincialism; to recollect that we are all subjects to one Queen; that we are all fellow workers together, and that, after all that is said and done, we are nothing more or less than a body of British gentlemen endeavouring to rule for their good a most interesting and intelligent race."

Lord Napier, of Magdala, at a banquet at Simla, in bidding Durand farewell, said emphatically, "When he lays down his office, his name will remain amongst the people as one of the benefactors of the Punjab;" and the newly appointed Lieutenant Governor himself replied, "I go to that province with all the stronger affection towards the people, because I had the honour of being one who fought against them; and certainly, if there be any remains of vigour or ability, or earnest devotion to the welfare of the people remaining at my time of life, it shall be devoted heartily to all that can be done for the welfare of the people of that province." The rule which was commenced under such bright auspices in June, 1870, was brought to a sudden and untimely end before the close of the year. Sir Henry Durand was making a tour through the States on the frontier of the Punjab, and on the 31st of December, being encamped near Tank, he wished to see the town. Taking the Nawab with him on his elephant, and followed by several members of his government and other officials, he proceeded to the gates; but there were two gateways, of which the second was too low for the howdah to pass under, and before the elephant could be stopped, there was a crash, and Sir Henry Durand was thrown to the ground. He was carried to the camp and recovered his consciousness, but his spine had been injured, and at eight o'clock on the evening of the 1st of January, 1871, he expired. He was buried not far from the place where he died, at the frontier station of Dera Ismael Khàn, and perhaps no more fitting spot could have been chosen as his last resting place, for, facing the Affghan hills and passes, in which as a soldier he first made for himself a name, he lies in this wild border land as if to guard the fair province which he had ruled so well.

The public loss sustained by his untimely death was universally acknowledged. The sorrow felt by all who had come in contact with him was due to the amiability and nobleness of his private character, to which a tribute has been paid in the following lines, written soon after his death, by another Anglo-Indian statesman, Sir H. Bartle Frere.

PERCY in blood, in spirit Hotspur's son,
Frank, brave, imperious—moulded in the form
Of those who our Third Edward gathered round,
When 'mid the chivalry of Scot or Frank
He bade, for England's banner, way be hewn—
Foremost where danger threatened. In the breach
As in the Council, steadfast, calm, and true;
Yet tender as a child to those in need,
And champion, aye, of widow and of maid;
With hate and scorn for naught but mean and base;
Holy in thought and word, and grave of mien,
As one who, on the edge of Life's dark sea,
Gazes to catch the light where dawns Eternity.

G. T. P.

PROFESSIONAL PAPERS.

PAPER I.

ON THE DRAINAGE OF WINDSOR CASTLE.

BY CAPTAIN GUN, R.E.

The alterations made recently in the drainage of Windsor Castle, which it is the object of the present paper to describe, had become necessary owing to the Act of Parliament passed in 1866, by which power was given to the Conservancy Board of the Thames to compel the diversion from that river of all sewage water, which had previously flowed into it. The Conservancy Board served notices, after the passing of the Act, upon the riparian towns using sewage outfalls, and also upon the authorities of Windsor Castle, which, though situated close to the borough of Windsor, was not connected with its sewage arrangements, but had a separate outfall. The attention of those responsible for the sanitary arrangements of the Castle was at once directed to the best means of effecting the object desired—the diversion of the sewage from the Thames. It will be well to see what was the nature of the problem they had to deal with, as the investigation will serve to illustrate the general conditions of similar enquiries.

Pl. I. Windsor Castle covers an area of $12\frac{1}{2}$ acres, not including the terrace on the north. The royal mews, which are adjoining, but at a lower level, cover $2\frac{1}{4}$ acres.

This surface of nearly 15 acres is in great part slated or paved, the roadways are steep, and the water falling on the whole runs off with great rapidity. Each inch of rainfall would produce about 220,000 gallons of water. The water supply of the Castle and mews is obtained by pumping from the gravel beds of the river Thames, and amounts to 150,000 gallons daily. Previous to the works about to be described all the water that was not required either in the Castle or the royal gardens passed as overflow into the main sewers, a constant quantity being supplied daily. A rainfall of 3 inches in one day, which is far from unprecedented, would produce therefore, with the water supply, 770,000 gallons of polluted water.

To carry this sewage and rainfall, there was a system of drains, as shewn in Pl. II.

The chief features of this system were the main drain from the Castle to the Cambridge Lodge on the Long Walk, and the cross drain from the Norman Gate to the East Terrace Garden.

The former of these drains is of 9-inch brickwork, 4 ft. 6 in. by 3 ft., and both are about 30 ft. below the level of the ground floor of the Castle. A subsidiary drain passes at about 20 ft. below the mews, and joins the others also at Cambridge Lodge. The fall of the main drain is about 1 in 40; the Castle is on much higher ground than Cambridge Lodge.

Into these drains were conducted a number of pipes of different diameters, conveying all the rain water and sewage of the Castle and terraces, with the exception of certain small areas of the latter, the rain water off which passed into receiving pits in the chalk, or down the slopes. The daily overflow from the fountain in the east terrace passed into these drains as well. This overflow consisted of the residue of the 150,000 gallons supplied from the wells daily, after providing for the wants of the Castle, mews, royal gardens, and for the flushing. The flushing was arranged by Captain Vetch, R.E. He provided three tanks for the purpose at the highest parts of the drainage system. Every morning at a given signal 15,000 gallons of water are discharged from these simultaneously; this quantity of water runs off in less than 20 minutes, scouring the drains most completely.

The main drain, marked Main Castle sewer, 1863, in the Home Park, received the contents of the above sewers. It is 2 ft. in diameter, and in the lower part of the park is 8 or 9 ft. below the surface. Its outfall is in the Thames.

The above system was designed and commenced by Captain Vetch, R.E., about 1846; previous to that time, the whole of the foul drainage was received into large cesspools formed in the chalk on which the Castle stands; these partly absorbed the liquid, and the remainder overflowed into surface drains constructed for the rain water, and leading into the Thames.

Captain Vetch's scheme included the construction of the "Crown sewer," into which the town was allowed, two or three years later, when the system was altered there, to pass its sewage. But it was not until 1863 that the "Castle sewer" was constructed for the separate reception of the Castle sewage.

The main sewer, made in 1846, was driven as a gallery under the foundation of the Castle, by the labour of a party of Sappers, under the orders of Lieut., now Colonel, the Hon. H. F. Keane.

The "Crown sewer," used previously to 1863, for the Castle sewage, is at a lower level than the "Castle sewer;" the drainage of even the lowest parts of the town being admitted into it. It commences at the Thames above the Eton bridge, and sluice gates only close it from the river, which can thus be admitted freely for flushing. The crown of the arch of the culvert is in the highest floods, fully 8 feet under water; in the lowest summer level of the river one foot above. After passing under the town, and receiving its drainage, the sewer falls into the Thames below Datchet, at much the same relative level to the water there as at its commencement. In this distance of two miles there is in fact in the culvert only the fall that the river bed has between Eton and Datchet, and the sewer is an underground canal cut across the neck of land formed by the loop in the river. Such a sewer as this is, in those months when floods prevail, under water at both ends, and the sewage is pent up, and has not a free escape. To obviate the risk of the sewer being burst by the pressure, overflow man-holes had been constructed in the Home Park, and the sewage often in the winter time came up and lay in the Park. Nor was this all—Frogmore House, in the Home Park, is one of the royal residences, and is a large and commodious mansion in which some of the royal family usually reside. It is situated too low to have been connected with the new "Castle sewer (1863,)" and remained in connection with the "Crown sewer," and hence this house was subjected to great inconvenience from the dammed up sewage.

There are several other buildings of importance in the Home Park, to the drainage arrangements of which allusion will be made farther on.

The drainage arrangements of Windsor Castle were, therefore, prior to 1866, very perfect, as long as the system of draining into the Thames was permissible, and the change which then became necessary was due to the legislation of that year with regard to the Thames; but the drainage of Frogmore House, and other low-lying buildings, was defective, inasmuch as it was connected with a sewer which, besides delivering into the Thames, was placed too low to run freely at all times of the year. It will be seen that the cases are distinct, but that a comprehensive scheme had to deal with each. There was practically but one method of disposing of the sewage of the Castle when cut off from the river, and this was to deodorize it by spreading it on land; practically but one method, because in 1867, the Royal Commission appointed to enquire into the Pollution of Rivers, of which, first Mr. Rawlinson and then Sir W. Denison was chairman, had come to that conclusion, and had decided that the various schemes of producing, by chemical re-agents, solid manures, were not developed sufficiently for practical purposes.

The conditions for a perfect sewage scheme for the Castle and Home Park presented themselves, therefore, simply thus: to collect the polluted waters from all the buildings comprised under both heads and to convey them to a site where they could be utilized and deodorized by passing over and through land on which were growing crops. Great attention was given by all concerned in the administration of Windsor Castle to the solution of the above problem. Two or three years were spent in the investigation of every scheme that could be suggested, and thorough examination of the Crown buildings and lands was made. It is needless to enter into the merits of every proposal made; it was at last decided, upon both *sanitary* and *economical* grounds, that the following general scheme met all the circumstances of the case. It should be stated that the principal features of it had been long advocated by W. Menzies, Esq., the able Deputy Surveyor of Windsor Park and Forest, whose local knowledge and special acquaintance with sanitary engineering, had enabled him to take early an advanced view on the subject.

This scheme consisted in separating in all the buildings the rainfall from the sewage, and in conveying the whole of the latter to the "Ham," an isolated piece of land between the main stream of the Thames and the "Cut," the navigable branch of the river. It was essential that the sewer conveying the sewage should be water-tight, since it would have to be laid in the gravel bordering the river, and the water in this gravel, being at practically the same level as the river, is in the flood-time of the latter close to the surface. This connection of the subsoil water with the river, prohibits the possibility of ever lowering the level in the gravel by any practicable scheme.

The first part of the scheme, the separation of the rain water from the sewage, had the additional recommendation of being in accordance with the views expressed by Lieut. Colonel Ewart, R.E., as special commissioner, in his report, in the year 1869, to the Home Secretary, on the "Drainage of Towns in the Thames Valley."

The Commissioners of Land Revenue asked that a Royal Engineer Officer might assist in the works, and with the consent of the War Office, Lieutenant (now Captain) Gun, R.E., serving in the Home District, was nominated by Colonel Keane, the Commanding Royal Engineer, to co-operate with Mr. Menzies in preparing the necessary plans, and in carrying out the works. The plans were prepared in 1871, and the works commenced in that year and finished in 1872 and the beginning of 1873.

Description of the Works.

In Windsor Castle itself, the work to be done consisted in separating the sewage from the rainfall; both these delivered into the sewers already described. The system carried out has been, that these sewers are in future to be used solely for foul waters, and that a completely new rain-water service has been constructed. On this principle, all pipes, whether of iron or earthenware, vertical, or horizontal, which conveyed sewage alone, have been left undisturbed; the down spouts, conveying rain-water alone, have been tapped at the foot, and joined with the new rain-water system; the mixed pipes, *i.e.*, those conveying both sewage and rain-water, of which there were about six, have been dealt with according to circumstances; in some cases a new soil pipe has been made, and connected with the sewers; in others, a new rain-water pipe brought down from the roof. The pure water drains are collected and conducted into the two main drains shown on Pl. II., which, meeting at the Cambridge Lodge, pass into a culvert, 24 inches in diameter, which again empties into the crown sewer, and by it the water passes to the Thames. It may here be explained, that this crown sewer will be eventually, necessarily, a simple pure water drain, since the sewage of the town of Windsor will have to be immediately removed from it.

The foul matters of the castle and royal mews, deprived by the above arrangements of the rain water, are conveyed by the existing drains and by the Castle

Sewer (1863) to a point A, where the new drain, an 18-in. pipe, is joined in; from that point to the river the Castle Sewer, 1863, is now dead. At the point B a man-hole is constructed; the new 18-in. pipe enters it at a level of 26·0′.* It issues at 4·5′ lower, at which level the Frogmore drain, a 12 in. pipe, can enter. Foul drains from the aviary, the Home Farm, and the kennels, are also taken into it. Farther on the drain from the Shaw Farm and Royal Gardens are admitted, being the last of the tributaries. The new sewer traverses the Home Park, passes under the Datchet Road, and under the Battle Bourne; at this last point a man-hole is constructed, and a safety overflow is provided into the Bourne stream. This overflow is of a double nature: the bottom of the 18-in. pipe is at the level of 16 8′, and the first overflow is 3 45 feet higher. This comes into action by means of a screw valve: at the level of 23·8′ is a self-acting overflow. The section Pl. No. VI., shows these arrangements. The 18-in. pipe is, of course, placed under pressure if either of these overflows comes into action. The main pipe passes across the Manor Farm, about 6 ft. below ground, to the sewage pumping station, where it empties into a reservoir. The average fall of the pipe from its commencement to the reservoir is 4 feet per mile; this, with an 18-in. pipe, gives a conveying power of about 60,000 gallons per hour of sewage water, calculated in the usual manner.

The reservoir is constructed on a plan worked out by Messrs. Simmonds and Ripley for the Eton Sewage Works, of which they were the engineers. Some small modifications are introduced, chiefly in the simplification of the arrangements for arresting the coarser substances of the sewage. In the Castle reservoir there is only a strainer, and on top of it a platform, on which a man stands to rake up the matter collected at the foot of the strainer. Pl. No. V. fully illustrates the reservoir. It is situated in the gravel of the Thames valley, here many feet deep; the level of the bottom of the reservoir is 16 ft. 7 in. below that of the ground line, 5 ft. 6 in. below that of the lowest level of the water standing in the gravel, 15 ft. 6 in. below that of the highest level 26·0′. It will be thus seen that the sides of the reservoir are under pressure from the exterior when the interior is dry, and the floods high; and from the interior when the reservoir is full, and the water outside low. The construction provides accordingly for resistance to both thrusts. The reservoir holds 20,000 gallons. From the reservoir the sewage is lifted by pumping power, and forced across the bridge over the "Cut" to the irrigation ground, on the "Ham." The pumping power is obtained from the river under the following circumstances:—

The Department of Land Revenue had obtained, in 1871, approval for a scheme for supplying the upper part of Windsor Park with water. Mr. Menzies was entrusted, as the representative of the Department, with the preparation and execution of the scheme. A well was sunk, in the river gravel, near old Windsor Lock † and the water pumped from it to the Park, a distance

* All levels are referred to a datum 38 feet above Ordnance datum.

† The water obtained from it is perfectly clean and sparkling; the level of the water in the well is approximately that of the Thames, which is distant about 25 feet; but the water drawn from the well is no doubt, in ordinary cases, the land water travelling to the river. After a long drought the river water might flow into the gravel, but, as a rule, the reverse would be the case.

of about three miles. The fall of the river at the Lock (3 ft. 8 in.) is used to work a turbine of 12 horse-power nominal; of this power 8 horse-power are required for raising the water to the Park, and the remainder, 4 horse-power, are appropriated to the service of the sewage pumps. The two schemes being under consideration at the same time, it was possible to make the above arrangement. The sewage reservoir is, it will be seen by the plan, a long way (425 yards) from the Lock and turbine, and a plan proposed by Messrs. Easton and Anderson, the eminent hydraulic engineers, has been adopted, for conveying the power from the turbine to the pumps at the reservoir. This consists in compressing air at the former place, in conveying it in a 2-in. pipe to the latter, and there making use of it to work a pair of air pumps of 3 horse-power. These, in the event of the turbine breaking down, are to be worked by steam, and a boiler is provided for the purpose at the reservoir.

On being lifted over the "Cut" bridge, the sewage is conveyed in a 6-in. pipe along the bank of the Ham, and there distributed over the land laid out for irrigation. There is a settling tank 20 ft. by 6 ft. by 3 ft. on this main-carrier, in which lime water or other precipitate can, if necessary, be added to the sewage.

The position and direction of the various carriers are shown on Pl. No. III.; they are entirely of iron. The extent of the farm is 15 acres, an area on which the sewage of the castle can be thoroughly deodorised, provided that no rain water is admitted into the sewage system.

The population of the castle, when full, is......	1,000
And there are horses and cattle	500

The general arrangements of the sewage system adopted, having been thus sketched, it is proposed to point out a few of the special features of the case, both in design and execution.

First, as regards the turbine, one-third of the power of which is, as above stated, devoted to pumping the sewage.

It is illustrated by Pl. No. IV. There were several difficulties in executing the culvert A, B; the soil to be cut through was of very variable texture. The top section is chiefly made of earth from the excavation of the Lock, then come some feet of Thames valley gravel; and then over part of the length a peat layer, about 8 feet below the surface; and which, communicating as it does, with the river, proved very troublesome. The mouths A and B of the culvert were strongly sheet piled, and the sides of the excavation as well. Some of the piles were easily driven, others very slowly, through the gravel bed. When the peat bed was entered upon, two of Appold's centrifugal pumps of 18 in. and 15 in. disc diameter, could not keep the bottom dry for laying ordinary concrete as a base for the invert. The concrete was, therefore, filled into old linseed bags, and these were laid, when half set, for the foundation like wool packs. The composition of the concrete was two parts of gravel, and one part of Burham cement. It is believed that the pressure squeezes the bags of concrete into a homogeneous mass. Mr. Leach, the Engineer of the Thames Conservancy, suggested this foundation, which the writer does not remember to have heard of before.

The brickwork was laid without much difficulty, except that one of the pumps was occasionally out of order, when the bricklayers were immediately drowned out of the works.

Since the turbine was finally fixed, it has worked regularly and smoothly, and does easily all that is required of it.

It is all important in such cases as this, where the fall of a river at a lock is made use of to obtain pumping power, that the conditions of the river above and below the lock be closely noted. There is a tendency in flood times towards equality in the levels of the upper and lower waters, and nothing but actual observation can in the least degree determine what will be the consequent loss of head resulting from this. At Bray lock, near Maidenhead, the floods run level over the weir and lock gates, the ordinary fall being 1 ft.; at the well-known Boveney lock above Windsor, there was only a difference of 1 ft. 3 in. in a high flood this winter (1872-73) against an ordinary fall of 4 ft.

The conditions at Windsor old lock are peculiar. It will be seen by reference to Pl. No. I., that the lock-canal is the string of a bow in the river, and that there is, therefore, a greater distance between the weir and the mouth of the lock than is usual, the effect being, of course, to enable the river to run off and lower before reaching this last point. The least difference of level in the high floods of 1872-73 was 3 ft.; the turbine being then under 8 ft. 6 in. of water.

By the construction of the weir, a sufficiency of water is provided at all times to keep the turbine culvert full.

The diagram Pl. V., Fig. 1, illustrates the principle of the weir; the upper part consists of sliding panels, to be lowered in flood, and raised in ordinary times.

The Commissioners of Land Revenue and Board of Works contributed to the re-construction of the old Windsor weir with a view to secure the above advantages for the supply of water and for the Castle drainage schemes.

Mr. Menzies has contributed this year a paper to the Institute of Surveyors, which deals more fully with the recent alterations in the locks, weirs, and overflows of the Thames, and which is well worth studying.

The air compressing pump in the turbine house was provided to be as follows: Horizontal double acting, with gun metal barrel, accurately bored to the diameter of 10 in., fitted with cast iron plungers, having double-capped leathers, and worked by a cast iron disc plate of 18 in. stroke, and wrought iron connecting rod. To be provided with the necessary suction and delivery valves, and to be capable of compressing to 35 lbs. pressure per square inch, sufficient air to work one engine at the drainage works (as after described).

The delivery main for conveying the compressed air from these pumps to the drainage works to be cast iron, 2 in. diameter, truly cylindrical throughout its length, laid solid, and properly jointed with lead and yarn. The line of this last is shown on Pl No. III. at the engine house.

The pumps are described to be in duplicate, on the vertical three-throw principle, each set to be provided with gun metal barrels, truly bored to the diameter of $7\frac{1}{2}$ in., firmly secured to the valve boxes, and worked by a cast iron three-throw crank of 15 in. stroke, with connecting rods of wrought iron, and buckets of cast iron, with double capped leathers.

The engines are in duplicate; cylinders $6\frac{1}{4}$ in. diameter, and 8 in. stroke, provided with metallic spring pistons and accurately fitting rods, valves so arranged as to work either by steam or air, without alteration.

The boiler (for use in case of a break-down of the turbine) on the Cornish single flue principle, 8 ft 9 in. long, 3 ft. 9 in. diameter.

The suction and delivery pipes to be 6 in. internal diameter, truly cylindrical throughout their length, laid solid, and properly jointed with lead and yarn. The end of each suction pipe to be provided with a rose or strainer, and a 6-in. self acting valve to be fixed on each delivery pipe close to the pumps, so that they may be examined at any time without emptying the main.

Two air receivers or containers, 2 ft. diameter, and 3 ft. high, formed of $\frac{3}{16}$ths in. boiler plates, to be provided and fixed, one in the boiler room at the drainage works, and one in the engine room at the lock, each with the necessary connections to join to the air main. The one at the drainage works to be provided with a gun metal safety valve, with lever and weights.

The pumping machinery is made self acting, by means of a float in the reservoir, which, working on a lever, regulates the power to be applied, and shuts it off entirely when the reservoir is empty.

There is a bridge* shewn on Pl. III., over the Cut. The pipe conveying the sewage is laid on brackets at one side. The main carrier is laid on the bank of the cut; a second main carrier is taken to the other side of the ground, which is laid in ridges and furrows, as shewn on Pl. No. III. The ridges are one chain apart, and there is a fall of 6 in. to the furrows. The carriers on the ridges are in iron of the section ∪. These are only laid to within a chain and a half of the ends of the ridges, the sewage being allowed to flow the remainder of the distance on the soil. The ground, though naturally tolerably well suited for the reception of sewage, needed a great deal of levelling; and it is well to call attention to the large expenditure of this part of the work, amounting to £84 per acre. It will be found, indeed, that this expense will be incurred in laying out most sewage farms, and is a material element of their large cost. In the present case, soldier labour was employed in a great measure. Lieutenant Colonel Sturt, the acting commanding officer of the 1st Battalion Grenadier Guards, quartered at Windsor, obtained with great readiness the permission of Colonel Higginson, C.B., the Major of the Battalion, for the employment of from 50 to 75 men for more than a month. They were in charge of Sergeant Dawson, who had been trained in executing field works at the the S.M.E. Chatham, and whose knowledge of levelling ground, thus acquired, was very valuable. The men were paid 1s. a day, and a pint of beer was issued to them on the ground. They worked six hours, exclusive of marching to and from the barracks, distant three miles. It should be added that owing to the great demand for workmen at the time in the vicinity, there was no competition with the labour market of the country.

The site of the reservoir had to be sheet-piled all round, the water standing

* The Thames Conservancy rebuilt this bridge in iron at the time of execution of the sewerage works, receiving a contribution towards it from the drainage works.

at that time (May, 1872) within 8 feet of the surface, and being in communication with the Thames through the gravel.

The excavation was pumped out by an Appold's centrifugal pump, and the concrete laid dry. The brickwork is in cement, one cement to three sand; particularly hard over-burnt stock bricks were used, as being less porous.

The main sewer to the reservoir is of 18 in. earthenware socket-jointed pipes, manufactured by Messrs. Doulton, of Lambeth; great care was exercised in their selection, about five per cent. being rejected for flaws. Its average depth below the surface is 6 feet. Portland cement with two parts of sand, was used for making the joints. Very great accuracy is needed in laying such pipes as these; three sets of boning rods were employed, placed about 50 yards apart along the line; the length of pipe (two feet) was lowered by a small gyn, and kept suspended, whilst a rod with a cross head was held on the top and brought into line with the boning rods; gravel was then placed under the pipe to make a true bed for it. The socket of the pipe previously laid was then filled with cement mortar, and the new pipe being lifted by the gyn, was shoved in so as to make a close joint by squeezing out the mortar. The joint was then completed outside and in. Each gang of labourers, with one bricklayer to make joints, laid 25 lengths—50 feet per day.

The sewer is provided with man-holes and ventilators; these latter being earthenware pipes opening above ground, or iron pipes taken up trees or buildings.

The main sewer up to the point B, Pl. I., one mile in length, was only one inch out of the calculated level at that point.

In the Castle itself, the work done was that of separating the rainfall from the sewage; having once adopted the principle that the main sewers should continue to receive the soil, and that the rain water service should be provided anew, there was no difficulty in execution.

There were some pipes which conveyed both rain-fall and sewage, as at (A) in Fig. 2, Pl. V.; the new pipe (B) was in this case brought down to carry the rain-fall, and a fresh one (C) carried up from the W.C., in order to compensate for the ventilation lost by cutting off the rain water pipe. This pipe (C) was carried up above the roof.

One of the principal collections of rain water pipes was made by driving in under the East Terrace, and tapping a collecting pit, which received the water from many of these pipes. Inside the castle it was necessary to lift the pavement along the passages of the offices, and to intercept many rain water pipes which delivered inside the building.

The drainage of one or two roofs was reversed by laying fillets in the gutters, so as to send the water down some pipe convenient to get at below.

The water falling on the Round Tower was got at by tapping the main pipe, conveying it down the centre, and taking a new pipe out through the outer wall under a window, where the thickness was moderate.

In one way or another, the whole of the rain water falling on the area of the Castle, with the exception of about 100 yards of roof, which it would have been too expensive to interfere with, was diverted to the rain water system, or sent down the northern slopes.

Much the same course was followed at Frogmore and at the other buildings; the rain water at Frogmore being conveyed into the lake.

The work was not put out to contract as a whole. Contracts were made for different portions of it; especially for the supply of the machinery and of the earthenware pipes.

The total cost was £18,000; the chief heads of the expenditure were as follows:—

	£
Purchase of land, of easement rights, compensation to tenants, &c.	1,984
Thames Conservancy, for re-building weir and bridge	800
Separation of rain water from sewage in Windsor Castle and other buildings	3,404
Construction of main drain	4,392
Reservoir	1,097
Pumping machinery and proportion of cost of turbine	3,302
Laying out irrigation ground and embanking	1,640
Preparation of plans and sundries	1,250

The work throughout was superintended by Mr. Menzies and the writer. They had the advantage of the assistance of J. W. Anderson, Esq., inspector of machinery to the War Department, in the preparation of the machinery contracts and specification. They were also indebted to Messrs. Ripley and Simmonds, surveyors and engineers of Windsor, for the free use of their plans of the Eton reservoir, and for suggestions derived from their experience acquired in carrying out that and other works. Colonel the Hon. H. F. Keane, and Colonel T. A. L. Murray, were Commanding Royal Engineers in London during the progress of the work.

H. A. G.

PAPER II.

OUR PRESENT KNOWLEDGE OF BUILDING MATERIALS AND HOW TO IMPROVE IT.*

By CAPTAIN SEDDON, R.E.

It may not be out of place to preface my subject by pointing out that the most successful architect, as well as the most successful engineer, I hold to be he who produces the best results out of the least expenditure on materials and labour, or rather workmanship, for I allude to the labour of the hands as distinguished from the labour of the head; for therein lies the great difference between scientific and unscientific construction, between true art and worthless imitation, spiritless copyism. The more we advance the greater becomes the expenditure on headwork, and the less on mere handwork and materials; the great brain problem of the day is how most successfully to economise both matter and force.

The principal charm to my mind in the work of the Mediæval builders, when comparing it with the architecture of Greece and Rome, is the evidence it always bears about it of headwork; the workmen stand there unbosomed before you, you seem to read their very thoughts, and to appropriate to yourself the pleasure with which they laboured to carry out their own ideas. You cannot look at one of the cathedrals of the Middle Ages without acknowledging to yourself that those builders strove to make the best use of the materials they found to hand. On the other hand, turn to a Grecian temple, and stately and beautiful as it undoubtedly is, perfect in proportion and in the refinement of its adornments, there is no soul, no life in it at all; there is plenty of labour of hands, mathematical precision of thought—thought of the architect but not of the workman—and materials regardless of cost; but in vigour of thought, in an appreciation of the true value of stone as a building material, and in constructive skill, the Grecian builders can bear no comparison with those of the Middle Ages. Give him but a few bones for his guidance, and an architectural Owen could almost reproduce the original, so rigid and exact were the laws which governed its growth, and fettered the fancies of its builders.

* A Paper read at the Ordinary General Meeting of the Royal Institute of British Architects, held on Monday, the 22nd April, 1872.

Engineers have to a greater extent than architects been compelled to study the nature and strength of materials, and especially of iron, which (used as it is by the former for every kind of work) has to be dealt with so as to economise both weight and material to the utmost, and to make the best possible use of its enormous powers of resistance to strains of every description. In fact, the extensive use of iron for constructive purposes may almost be said to have given birth to the profession of civil engineering as distinct from that of architecture, the result of which has, I think, been a tendency to too exclusive a cultivation of art on the one side, and of science on the other, to the manifest disadvantage of both professions.

Inasmuch as the architect aims at the beautiful in his constructions, as well as the useful, his profession is of a more elevated character than that of the engineer; for by assisting to cultivate the public taste, he leads towards the source of all beauty and purity. Engineers, confining themselves too closely to one idea—namely, the theoretical perfection of their work—have fully met the want that gave them birth, have shown how maximum results may be obtained from a minimum expenditure on labour and materials; but in mastering science they have too much neglected art, and even at times justified the absence of any aim at the beautiful, by affecting to rise above such ideas into the regions of the stupendous and the grand; but, unfortunately, in minor undertakings, in little works which cannot aspire so high, we still find the same absence of any attempt to please the more cultivated feelings of our nature; or if the attempt is there, it is mostly too evident that a given sum has been expended upon purchasing a mask to hide not the loveliest of structural details below.

That there always must be a radical difference between the two professions of architect and engineer is clear, according as the tastes and bent of different minds lead individuals to devote their energies, more or less exclusively, to certain kinds of work. I conceive, however, that members of both professions would be better for working more together, for a freer exchange of ideas; the country at large would derive more pleasure as well as benefit from works of engineers, whilst the employment of architects would be looked upon less in the false light of an expensive luxury beyond the reach of all but the favoured few, if they were regarded more as scientific constructors, who, combining a knowledge of, and true feeling for, art, were sure to produce a better built, better planned, more healthful, more beautiful, and less costly building than could be obtained without their aid. At any rate with regard to the last point, in aiming at economy, in striving to obtain the best results from the least expenditure on materials and hand labour, both architects and engineers stand on common ground; but, in order to succeed in this aim, it is necessary that we should be thoroughly acquainted with the capabilities of all the materials we may require to make use of, for resisting every kind of stress to which they could be subjected.

Now, the question which I mean to raise this evening is, whether we are yet sufficiently acquainted with the properties and strength of the different materials in common use for building purposes to enable us to employ them to the best advantage, or to allow of our calculating with accuracy the amount of material necessary, in every part of a structure, to meet the different stresses called into play?

It may be said by some—What more information do we want than that already within our reach? There are hand-books enough, in all conscience, with copious tables, giving the strength of all kinds of materials under every description of stress, and formulæ for calculating the requisite dimensions of beams, columns, &c., of different forms, and under varied conditions: surely we are in possession of all the information any one could possibly require. Nevertheless, I think it must be admitted, on a little reflection, that the present state of our knowledge in these matters is, in face of the boasted enlightenment of the nineteenth century, by no means so satisfactory as at first sight might be imagined; or in any way sufficient to warrant our resting content without making any further researches.

Most of the data upon which calculations have hitherto been based, have been derived from experiments made on picked specimens, too small in size, and too free from such ordinary defects as are sure to occur in larger specimens, to give us very reliable grounds to go upon; the result being that we are forced to supplement our defective knowledge by using large factors of safety; or, in other words, by not straining the material used to anything like its estimated powers of resistance.

I know that it may be argued, on the other hand, that any slight defect would weaken a small section more than a larger one, and therefore that the great difference of strength attributed to the careful selecting of specimens might, in a great measure, be counterbalanced from the certainty of there being some slight defects, even in the most carefully selected specimens; but in this case we are only dealing with probabilities, and not with ascertained facts.

Again, the results obtained from different experiments made by Muschenbrock, Rondelet, Rennie, Barlow, Hodgkinson, Fairbairn, and others, vary so considerably, that little or no reliance can, in many instances, be placed upon them; nor are these discrepancies difficult to account for, when we consider that the experiments were made by many different hands, with different degrees of care, on a comparatively limited number of specimens, and that the means employed for carrying out the experiments differed in almost every instance, being often of such a kind as to be incapable of recording any accurate results. Let us glance at some of the discordant results obtained, in order to see how much value ought to be attached to them.

TIMBER.—Taking the subject of *Timber* first, I cannot, perhaps, do better than quote from a valuable little treatise lately published by Mr. B. Baker, C.E., "On the Strength of Beams, Columns, and Arches." At page 127 he says:—

"Unfortunately, most of the careful experiments of Tredgold, Barlow, and other early investigators, were made on small pieces of timber, straight grained, and free from knots and other defects, a condition favourable, it is true, to the comparison of the results of mathematical investigation with those derived from direct experiment, but, on the other hand, leading to errors of much greater moment in actual practice, since (as every workman knows) a piece of timber uniformly sound throughout can never be reckoned upon." He then goes on to show the per centage of loss of strength due to the inevitable defects in large scantlings, as follows :—A piece of English oak 2 in. long and 1 in. square, gave a result equivalent to a breaking weight of $8\frac{1}{2}$ cwt. applied at the centre of a 1 in. square bar, supported on bearings 12 in. apart, giving a calculated stress on the extreme fibres of the bar equal to 7·6 tons, or 17,024 lbs. per square inch, a surprisingly high, and, as far as practical cases are concerned, a palpably exaggerated result. Whereas, taking a larger scantling of oak, 11 ft. 9 in. long, and $8\frac{1}{2}$ in. square, the calculated stress on the extreme fibres, when rupture took place, was only five tons, or 11,200 lbs. instead of 17,000 lbs. per square inch; and a larger beam still, 24 ft. 6 in. long, $12\frac{1}{4}$ in. deep, and $10\frac{3}{8}$ in. wide, gave a result equivalent to less than one-third of that given by the small selected piece. He then says :—" This reduced amount shows that the average strength of the timber in this large beam was less than one-third of that in the small selected piece; and we think no further illustration is required to show the necessity of neglecting the majority of experiments made on small scantlings of oak, when deducing rules for practical application. We find the same conclusions hold good with reference to Riga, Memel, pitch pine, and other soft woods," the standard bar 12 in. long by 1 in. square, giving a maximum stress on the fibres of $3\frac{1}{2}$ to $4\frac{1}{2}$ tons per square inch, whilst experiments on a beam 15 ft. long and 12 in. square, give a maximum stress of only $2\frac{1}{4}$ per tons per square inch.

If we turn to Molesworth's Handbook of Engineering Formulæ, and Hurst's Architectural Surveyor's Handbook, both of which are books purporting to supply all the latest information brought up to date each year, we find the value of the constant, to be applied in the formula for beams under transverse stress, given as 5 for English oak, 5 cwts. being taken as the central load required to fracture a standard bar, 12 in. long and 1 in. square; although the tensile strength of oak in lbs. in Molesworth's Handbook is given as 17,000 lbs., which would give $8\frac{1}{2}$ cwts. instead of 5 cwts. as the central breaking load. Professor Rankine, in his " Rules and Tables," gives 10,000 to 19,000 lbs. per square inch as the tensile strength of oak, and 12 to 14,000 lbs. for fir or pine.

Now let us glance at the crushing strength of timber, as given by different experimenters.

Rondelet gives the crushing strength of pine as 54 to 62 cwts. per square in., and that of oak as 45 to 54 cwts.

Tredgold takes 36 cwts. for both.

Rennie gives the strength of pine at 14 cwts., and of elm as low as $11\frac{1}{2}$ cwts. per square inch.

Hodgkinson gives 92 cwts. for elm, 90 cwts. for oak, and about 54 cwts. for pine.

Lastly, I have here the results of some experiments made by Mr. Kirkaldy, on two logs 20 ft. long, and about 13 in. square, one of white Riga, and the other of red Dantzic fir, which show, in the first case, a resistance to crushing of 17·5 cwt., and in the last of 15·5 cwt. per square inch. Both balks failed by crushing, the lateral deflection not exceeding ·64 of an inch in either case.* These results approximate closer to those made by Rennie than any of the others.

Here is a mass of conflicting evidence, notwithstanding the apparent simplicity of the subject; and yet it is by no means as simple as it seems. The conditions were no doubt very different in each set of experiments; the apparatus employed was different, there were different observers, and therefore it is not to be wondered at that the results arrived at differ. In fact, the seasoning alone of the specimens would at once account for a great part of the difference; for green timber, from the moisture in it reducing the lateral adhesion of the fibres, has not more than half the strength of dry timber, and yet if artificially overdried, a considerable loss of strength would be the result.

With regard to the transverse strength of timber beams especially, though the same remarks apply to those of iron or any other material, what would appear to be an important element in their strength, though hitherto omitted from all calculations, is the lateral adhesion of the fibres to each other.

It is evident that, as the extension of the fibres varies according to their distance from the neutral axis of the beam, as the beams bends, the fibres, if free to move, would slide upon each other, which sliding is resisted by the adhesion of the fibres to one another, thereby increasing the resistance of the beam both to deflection and breaking. For instance, if a beam is supported at each end and loaded, it will assume the form shown in Fig. A, Pl. VII. If, however, it were conceived to be made up of a number of thin layers, it would assume the form shown in Fig. B, Plate VII., the difference being due to the resistance of the fibres to horizontal shearing, in addition to their resistance to direct tension and compression. The means of measuring this force is given by Rankine, at page 88 of his "Applied Mechanics." Mr. Baker, C.E., in his work "On the strength of beams, columns, and arches," pages 8, 9, and 10, goes into this subject, and affirms that the neglect of this force in the beam leads to errors of any amount up to 190 cent., being little or nothing in iron girders, where the bulk of the metal is collected together in flanges as far as possible from the neutral axis.

IRON.—I now come to the subject, and a most important one, of iron. Notwithstanding the great advance which has of late been made towards a more perfect acquaintance with the properties of irons of different classes, and notably by means of the numerous experiments made by Mr. Kirkaldy, and the stimulus which has been given to the manufacture of high class irons, by the rival contests between iron guns and iron shields, it must be admitted, even by those who have made it a subject of special study, that there is very much yet to be learnt about iron; whilst, if we except a small circle, whose special employment has caused them to follow with interest in the track of every experiment which could throw any light upon the nature and properties of the material with which they are chiefly called upon to deal, there is a general lack of know-

* See Appendix 1.

ledge about the whole subject, besides much misconception, which the clear proof of practical experiment will alone be able to sweep away.

As a building material, iron is day by day forcing its way everywhere, and many, who not long ago, would have set their faces against its use in structures aiming at a high class of art, no longer hesitate to call in its valuable assistance in order to solve constructive problems which would be beyond the reach of wood, brick, or stone, at any rate within any reasonable limits of expenditure. Such being the case, it is essential that its properties should be thoroughly understood by all those who are likely to make use of it for constructive purposes, and that they should not merely order a girder, for instance, to carry a given load, leaving the designing of it to the manufacturer or his agent, whose interest it is to run up the weight, and hence the price, at the expense of quality and good workmanship.

It may safely be said that there is no material so dangerous to trust to, without a full knowledge of its behaviour under different conditions, than iron; whilst there is none which varies so much in quality, or in the manufacture of which there is more knowledge, experience, skill, and care required, or which admits of more deception being practised upon the unwary, by unscrupulous and dishonest manufacturers.

Now, I think that, beyond the difference between cast and wrought iron, and the inferiority of the former, when exposed to the effects of sudden shocks, there is very little accurate knowledge on the subject of the properties and powers of resistance of different classes of iron under varying conditions of stress. Their behaviour under different circumstances, such as tension, compression, shearing, bending, torsion, either suddenly or gradually applied, varies so widely according to the description of the iron under trial, that the strongest proof which could be adduced of the necessity, for a far wider acquaintance with the subject is given by the ordinary formulæ in use for calculating the strength of iron girders, &c.

Turning to "Hurst's Architectural Surveyor's Handbook" as a likely source from which a formula might be taken for calculating the strength, or the requisite dimensions of, say, a plate girder, we find the following formula, given for ascertaining the central breaking weight of a plate girder, viz. :—

$$W = \frac{C\,A\,D}{L} \text{ in which}$$

A = area of tension flange in inches;
D = depth of girder in inches;
L = length of bearing in feet;

and a constant C, in this case taken equal to 6, is made to include such a variable quantity as the breaking strength of wrought iron per square inch of section, without one word of explanation as to the quality of iron to which this constant is specially applicable. Nor is the corresponding formula in Molesworth's "Engineering Pocket Book," one whit better. If we analyse the above formula, we shall find the tensile strength of the iron to which the constant is applicable is not more than 18 tons per square inch; for L being in feet, and A and D in inches,

$$\frac{12 \text{ L W}}{2 \times 2} = \text{C A D}$$

$$3 \text{ L W} = \text{C A D}$$

$$\text{W} = \frac{\text{C A D}}{3 \text{ L}}$$

in which for C to = 6, the value laid down, the tensile strength must equal 18 tons.

Such formulæ, to those who are unable to unravel them, and see how they are arrived at, are but a delusion and a snare; they leave out of consideration the varying resistances of different classes of iron, and encourage the false idea that the strength of wrought and cast iron, or steel, may be safely represented by constant quantities.

In point of fact, we might ignore altogether the ultimate strength of a girder, since it is never, in practice, intended to be loaded so as to bring it anywhere near the breaking point; in addition to which, the ultimate strength of iron is, by itself, no proof whatever of its suitability for the work it may be called upon to perform. What really would be quite sufficient for us to know is, the degree of elasticity combined with the elastic limit of the metal employed; the former being measured by the amount of temporary alteration of form the metal will allow of under a temporary stress; and the latter by marking the point beyond which, under uniform increments of stress, the visible work done, such as compression or tension, keeps sensibly increasing, instead of remaining sensibly uniform, and beyond which the alteration of form becomes permanent. When strained beyond this point, which is its elastic limit, the metal is permanently injured, and its power of resistance decreases in an accelerating ratio, until it finally gives way altogether.

The testing of iron, however, for its elastic limit, is a matter of great delicacy, more especially as it is necessary to observe its reduction of area, or elongation, at the moment it reaches its elastic limit, and for this reason the breaking strength of iron is adhered to in practice, as giving, when observed in combination with its alteration of form, all the information required.

The degree of elasticity required in iron depends entirely upon the nature of the stress to which it is to be subjected, as whether the load upon a girder is to be dead or live, and how the latter is to be applied, namely, gradually or suddenly. If, then, we take proper steps to ensure the use of an iron sufficiently elastic for our purpose, and limit the stress to be put upon any of its fibres, so as to keep it well within the elastic limits of the particular iron employed, we may be sure of steering clear of any possible failures, except such as might arise from faulty design or faulty workmanship. Keeping these points in view, formulæ should be used in which the maximum stress to be put upon the metal takes the place of constants. Every one would then know the amount of stress they were actually putting upon the iron, and would take care that a proper class of metal, capable of safely resisting that stress, was made use of. Instead, then, of the formula already condemned, we might safely use the following, viz.:

$$\frac{W\,l}{4} = f\,A\,D \text{ or } W = \frac{4\,f\,A\,D}{l}$$

in which W = load at centre of girder in tons.
l = span in inches.
A = area of tension or lower flange, in inches.
D = depth of girder in inches.
f = limiting stress in tons per square inch, which for railway bridges exposed to the sudden shocks of a live load, is fixed by the Board of Trade at 5 tons for tension, and 4 tons compression.*

The load and span being known, the requisite dimensions of the girder may thus be readily found; or the girder being given, the load it can carry, subject to the particular limits of stress which may be laid down, can be ascertained. In this case the web of the plate girder, being thin, is not taken into account, but merely calculated to take the shearing stress; but in rolled iron girders, and other forms in which, from the amount of metal in the web, it would not do to neglect it, the bending moment due to the external forces must be equated with the moment of resistance of the beam, arrived at by finding the moment of inertia of the section of greatest stress, a process which is a little more troublesome. The girder having been designed, the remaining points to be attended to are to ensure sound workmanship, and an iron, capable, both as regards strength and elasticity, of taking with safety the stresses to be put upon it.

In order to insure our getting a suitable class of iron, it becomes necessary to have it properly tested. Let us suppose that some wrought iron tension bars are required, and that it was specified that the iron was not to break under a strain less than 23 tons to the inch, and supposing their actual breaking strength turned out to be 25 tons to the inch—that fact alone would be no guarantee that the iron was fit for the purpose for which it was required. If the elongation of the bars before fracture, or the reduction of the area at the section of fracture, was next to nothing, the iron could not be relied upon; though standing an exceptionally high tensile strain, it would be hard, brittle, and wholly unfit for use where it might have to resist the sudden shock of a live load.

The elasticity or ductility of the metal must therefore be ascertained, in addition to its direct tensile or compressile strength. In testing wrought iron for tensile strength, this is most readily done by noting the reduction of area at the point of fracture, in addition to the force required to produce rupture. So that, in drawing up a specification for wrought iron work, it is quite sufficient to specify that the iron shall be capable of bearing a given stress per unit of section, slowly applied, with a reduction of area at the point of fracture equal to a

* This is not quite correct, as the rules of the Board of Trade, based upon the recommendation of a Royal Commission, specify 5 tons per square inch, both in tension and compression.—EDITOR.

certain per centage of the original section, depending on the quality of iron required; or, which amounts to the same thing, that the iron shall bear a certain stress per unit of fractured area. The best relations between the original and ultimate length of bars of iron of different classes, broken under slow tension, or their original and ultimate sections of fracture, and their breaking strains, with regard to the different purposes for which the iron may be required, can only be ascertained by a most complete and careful series of experiments. I am, however, enabled to lay before you the results of a great number of experiments made by Mr. Kirkaldy, which have, so far as they have gone, been arranged by him in tables for the special use of the engineers of the Public Works Department in India, in drawing up specifications for wrought iron work:—

In the Table, irons of different well-known brands are classed under the letters C, D, E, F, G, according to their ultimate strength and elasticity; in addition to which there is a model clause for insertion in "Conditions of Contract," which, with but slight modifications, would be applicable to any contract.

TABLE B.

SCALE OF TENSILE TESTS FOR IRON OF VARIOUS QUALITIES.

Description.	Class C.		Class D.		Class E.		Class F.		Class G.	
	Ultimate stress per square inch.	Contraction of area at fracture.	Ultimate stress per square inch.	Contraction of area at fracture.	Ultimate stress per square inch.	Contraction of area at fracture.	Ultimate stress per square inch.	Contraction of area at fracture.	Ultimate stress per square inch.	Contraction of area at fracture.
	Tons.	Per cent	Tons.	Per cent	Tons.	Per cent	Tons.	Per cent	Tons.	Per cent
Bars, round or square	27	45	26	35	25	30	24	25	23	20
Bars, flat	26	40	25	30	24	25	23	20	22	16
Angle and Tee or T	25	30	24	22	23	18	22	15	21	12
Plates, lengthway	24 } 23	20 } 16	23 } 21½	15 } 12	22 } 20½	12 } 9½	21 } 19½	10 } 7½	20 } 18½	8 } 5½
Plates, crossway..	22	12	20	9	19	7	18	5	17	3

N.B.—Classes A B are reserved for any special qualities of Iron which might be required at any future time.

SWEDISH BARS.

Ultimate Stress per square inch } 22 tons. Contraction of area at fracture } 60 per cent.

Testing clause to be inserted in "Conditions of Contract":—

'3.—The iron to be of such quality as to stand the following tests:—

Ultimate Tensile Strength per Square Inch.	Average Tons.	Contraction of Area at Fracture.	Average per Cent.
Bars, round and square	. . .	Figures from Table	. . .
Bars, flat	. . .	of Qualities to be	. . .
Angle and Tee	. . .	inserted in the	. . .
Plates, lengthway	. . . }	blank spaces	. . . }
Plates, crossway	. . . }		. . . }

"4.—The Superintendent of Stores, or his deputy, will select materials representing 4 per cent. of the value, from which will be cut pieces 20 in. in length, and of plates and sheets 20 in. by 18 in. These pieces, after being stamped at or near the ends with the Superintendent of Stores' stamp, in addition to the maker's brand, will be sent to Mr. David Kirkaldy, Testing and Experimenting Works, The Grove, Southwark Street, London, S.E., to be tested and reported upon by him to the Superintendent of Stores.

"The iron will be accepted, although under the above specified strain, provided the contraction of area at fracture is the same per centage higher, or in other words softer iron than that specified will be accepted.

"In order to avoid expense and delay arising from rejection of materials, the attention of contractors is particularly requested to the foregoing tests, which will be strictly enforced in all cases.

"The contractor will be required to supply and deliver the materials, but the cost of testing will be borne by the India Store Department."

There are many obsolete notions about iron which still retain their places in specifications, such as "all castings to be of soft grey *cold blast* iron," and instructions laid down which are ignored by manufacturers, and any deviation from which could not be detected. All that is required with wrought iron is a compliance with the tests for strength and elasticity, and if these are satisfactory, it matters not to the architect or engineer how the metal has been manufactured, or what brand it bears. By limiting the stress to be put upon it, and then taking the proper precautions to ensure getting a good and suitable class of metal, a great stride will have been made towards a sound method of dealing with iron for constructive purposes.

I might here mention that it is useless to specify that girders, when tested under a given load, shall not take more than a certain amount of permanent set, seeing that the manufacturer could, if he chose, take the permanent set out of them beforehand, by loading them with the test load, so that when tried after delivery they would show no permanent set whatever. I have here the results of two interesting experiments made by Mr. Kirkaldy, one on a wrought iron plate girder, 23 ft. 2 in. between the supports, which broke under a force of 40·1 tons applied at the centre; and the other on a cast-iron girder, 18 ft. between the supports, which broke with a force of 45·19 tons; but as they will be embodied in my paper you will be able to examine them at leisure.*

In order to ascertain the quality of the cast iron used—for instance, in cast iron girders—the test bars usually specified to be cast at the same time, and from the same heating, as the girders themselves, should, if possible, be cast on

* See Pl. VIII.

to the girders, and only detached in the presence of the architect or engineer, or person appointed for that purpose. These bars are usually 2 in. by 1 in. and 4 ft. 6 in. long, and are afterwards tested under transverse stress; but it is a question whether it would not be better to cast pieces to be tested under direct tension and compression.

Most people would, I think, condemn an iron which showed a crystalline fracture, as totally unfit to resist tensile strains or sudden shocks; and yet that crystalline fracture, might be due either to the shape of the specimen experimented on or to the mode in which the breaking force was applied, for iron of a superior quality even, when broken by a sudden shock, will present a crystalline fracture, from the fibres not having time to draw out, and therefore breaking short across. For instance, here is a specimen of bar-iron showing a crystalline fracture with no diminution of area, having been torn asunder by the explosion of a charge of gun-cotton; whilst this specimen, which is a piece of the same bar which I broke under a gradually applied tensile strain, gave a highly fibrous section, with a very great reduction of area, indicating a soft, ductile iron. I have also brought some armour bolts which have been broken under the shock of an eight-ton hammer falling a height of 3 ft. 6 in. Those which were of a sufficiently soft, ductile iron, drew out before breaking, which they only did after ten or eleven blows: while those rejected on account of the hardness of the metal, broke, in some cases, with only one blow. That the best of these irons broke with a fibrous fracture is, however, no proof that under a more instantaneous rupture they would not snap without drawing out, and show a crystalline fracture. It is possible that if the most ductile of these bolts had been broken by the more instantaneous force generated by an explosion of gun-cotton, the fracture might have been crystalline instead of fibrous.

Then again, the effects of different degrees of temperature upon the ductility of irons of different qualities is also a subject requiring further investigation. We often hear of the crystallisation of iron under the effects of frost, which means that it is apt to snap and show a crystalline fracture; but this is due merely to a loss of ductility, causing it to break without any extension of the fibres. We know that under great heat wrought iron loses its elasticity, but becomes perfectly ductile, regaining its elasticity, but losing its ductility as it cools. Different classes of iron, no doubt, lose their ductility at different degrees of temperature, when they become brittle and liable to break off short under any suddenly applied force. Experiment may in time give us some definite means of deciding the best class of metal to use in hot or cold climates respectively, though we know sufficient at present to prevent our using a hard metal where exposed to extreme cold. Wrought iron will also lose its ductility if, as is often the case in heating rivets, it is burnt by being left in the fire too long. A first class rivet when taken out of the fire and allowed to cool may be nicked with a cold chisel and then broken across by a blow of a hammer, and, if it has not been left in the fire too long, will show a fibrous fracture, but if burnt the fracture will be crystalline. If proper attention is not paid to this, much injury may be done to riveted work by too large a number of rivets being heated at a time, in order to save trouble. In riveting up the ironwork for forts, a foreman of works is appointed specially to watch the riveting, twenty minutes being the utmost time 1-in. or $\frac{7}{8}$-in. rivets are allowed in the furnace; some are put aside to be tested, and any showing signs of burning are rejected. Other causes may perhaps also tend to reduce the ductility of iron, such as constant vibration and tension combined; but this, in the absence of any direct proof, is mere speculation.

Putting aside the quality of the iron as well as the nature of the breaking force, a crystalline fracture may be caused by any sudden diminution in the sectional area of a bar, such as is made by cutting a thread on a bolt, so that the same iron, exposed to the same stress, may be made to show a fibrous or crystalline fracture by merely altering the shape of the specimen.

The best shape to be given to different materials, according to the work they have to do, is another question as yet but little inquired into, but one which is of great importance in designing iron structures, as shown by Mr. Kirkaldy's experiments, and, practically, in what are termed the Palliser bolts, for attaching iron plates to their backing. The use of a minus thread on these bolts, or a thread cut into the bolt, and so reducing its effective area between the threads, had the effect of concentrating the work done upon such a small length of the bolt that the fibres very soon reached their elastic limit, and the bolts gave way. This was remedied by reducing the shanks of the bolts so as to relieve the weak parts between the threads, by spreading the work over a greater length of fibres, thereby obtaining increased strength, with an actual reduction of metal.

Again, a law has been laid down, and universally accepted, derived from one or two experiments made upon iron of a certain class, that iron under tension extends $\frac{1}{10000}$ part of its length for every ton per square inch put upon it. Is this true for all qualities of iron, and for bars of all lengths? I think there is one person, at least, present who would, without hesitation, answer "*No.*"

Some few experiments have lately been made by Mr. Kirkaldy on long bars under tension and compression, and the results when published will be very interesting; but it is to be hoped that many more such experiments may be made, and on different classes of iron.

With regard to the resistance of wrought iron to compression we have very little satisfactory evidence, the whole question depending on the pressure under which different classes of iron begin to yield and sensibly alter their form; for if too short to bend or buckle as it sets up, the area of resistance is increased, and with it the force required to compress it; which has led to an erroneous idea, amongst some, that wrought iron is stronger under compression than under tension.

I will now leave the subject of iron, already drawn out to too great a length, with the hope that before long an accumulation of facts, derived from careful experiments, may clear up the many uncertain points connected with it.

STONE.—Passsing on to another material, let us see whether we ought to rest satisfied with what we know about building stones.

Here again, the majority of experiments made have been based upon very small specimens, such as small cubes under compression, whilst the recorded results vary with each set of experiments, according to the amount of accuracy capable of being arrived at by the machinery made use of, as well as the skill and care with which the experiments were made and recorded.

If we take a stone which has been more largely used perhaps than any other, namely, Portland, we learn from Barlow that its crushing strength ranges from about 1384 lbs. to 4,000 lbs. per square inch, whilst in the experiments made by this Institute, and recorded in your Sessional Papers for 1864, the mean resistance to crushing, per square inch, arrived at was, for 2 in. cubes, 2,576 lbs.; for 4 in. cubes, 4,099 lbs.; and for 6 in. cubes, 4,300 lbs.

According to Rennie, its crushing strength may be taken as 3,729 lbs. per square inch, which has been followed by Molesworth in his "Handbook," whilst in Hurst's "Handbook" it is given as 2,022 lbs. per square inch.

Now, the many varieties of Portland stone, apart from any different method or course pursued in making the experiments, and the amount of seasoning the blocks had undergone—all points which should be carefully recorded—would fully account for the manifest discrepancies between these results; in addition to which, the direction of the natural bed of the stone, which in a small block of Portland might escape detection, would no doubt make a considerable difference. For instance, turning to some experiments by Mr. Kirkaldy on the resistance to thrust of Doulting stone (a Somersetshire oolite),* which I believe to be the only known experiments on this point—if we except two on York paving and Bramley Fall stone, recorded by Rennie, in which the crushing strength both with and against the strata are given as precisely the same, a coincidence too good to be true—the advantage of laying the stones on their natural beds is considerable, increasing rapidly with the increase in height of the block, in proportion to its sectional area, which, I think, is what we should naturally be led to expect, if we look upon the block as approximating, more or less, according to the amount of lamination in the stone, to a number of thin columns placed side by side. More experiments, on a larger variety of stones, are much wanted to throw additional light on this subject.

With regard to the supposition that the crushing strength of stone increases with the size of the blocks under trial, there has as yet been too little proof put forward on which to lay down any law. In fact, the few experiments made by Mr. Kirkaldy, bearing on this subject, some of the results of which have been placed at my disposal, go to prove that there is no increase in the resistance to crushing, consequent upon increase in the size of the blocks.

With regard to another of the oolites, namely, Bath stone, there is, I think, a good deal of misconception, which a careful series of experiments would soon clear up. For instance, Farleigh Down, being a little more expensive than Box Ground stone, is very generally looked upon as the best and strongest description of Bath stone for outdoor use, and is accordingly very often insisted on in specifications; the fact being that, on account of the stone being more

* See Pl. IX.

difficult to get out of the quarries, especially in large blocks, the price runs a little higher, whilst in strength or endurance it is not known that it can claim any precedence over Box Ground stone. From the experiments already referred to as recorded in your Sessional Papers, it would appear that Corsham stone is considerably stronger than Box Ground, though this is opposed to the results of other experiments. The durability of Bath stone mainly depends on its being placed on its natural bed, which can only be detected by an experienced eye, or by working the stone; though when not so placed it soon reveals the secret, especially where exposed to the weather, by its cracking and peeling away on the face.*

Much also depends on its being well seasoned, or air dried, before being put into the work, therefore the stone should only be got from quarry owners who keep large stocks of seasoned stone on hand. If quarried in the spring of the year, and stacked at open order during the summer weather, it is doubtful whether Corsham stone is not well able to resist the weather, though it is generally considered fit only for indoor work.

Artificial drying, which has sometimes been resorted to, should not be allowed. In one case a large quantity of picked Bath stone, which had been dried by heat, had to be condemned, and I believe led to a lawyer's bill, in consequence of the breaking up of the stone under exposure to the weather, owing, I fancy, to the unequal contraction and expansion of the dried and hardened surfaces, and the soft and green interiors of the blocks. I have seen stone, which had worn well when exposed to the weather, crumble away on being shifted to the inside of a house.

With regard to sandstones, the information contained in architectural and engineering handbooks is next to nothing; in fact, in Molesworth, the whole subject of sandstones is comprised in the information that their crushing strength is 5,000 lbs. to the square inch, which, being an easy round number to remember, might with equal reason be adopted as the crushing strength of all stones.

Very little is known with regard to the transverse strength of different kinds of stone, though there is no doubt that some are much more capable than others of taking a bending stress.

Stone is a material specially unsuited to resist any stress except compression, and it is the true appreciation of the nature of stone as a building material, by the almost exclusive use of it to the best advantage, namely, under compression, by the mediæval builders, that, to my mind, marks their great superiority, as scientific builders, over their predecessors of more refined classic ages.

In practice, however, we constantly find stone subjected to bending stress, and that further information under this head is required, struck me very forcibly some little time ago, on seeing some stone stairs, two stories high, being carefully propped up with wood, many of the steps having split right across close up to the wall. The steps were feather-edged, of Portland stone, $11\frac{1}{2}$ in. treads, and $6\frac{1}{4}$ in. risers, and had been exposed to the ordinary traffic of an office for

* This is not true in all cases, for projecting undercut mouldings and copings should be edge-bedded, the natural bed being placed parallel to the direction of the side joints.

about sixty-two years. The treads being much worn, a mason had been at work cutting them down at the top, preparatory to fixing an iron nosing, and filling the treads up level with asphalte, when the step he was at work on cracked close up to the wall, probably from the jarring caused by the strokes of the chisel; shortly after, several of the steps above also cracked, being no longer supported by those below, and being evidently unequal to do the work suddenly thrown upon them. Stairs with the steps only supported in the wall at one end are of constant occurrence, and serious accidents have sometimes occurred from their sudden failure.

Enough has been said, I think, to prove that more knowledge is required as to the special qualities of different kinds of stone, and their applicability to particular uses; but there is still another point about which there is not at present any certain knowledge, namely, to what extent the shape to which stones are cut, and the manner in which they are bedded, affects their strength. Some few experiments on these points have been made by Mr. Kirkaldy, at the instance of one of your fellows, some of the results of which have, I believe, been already placed before you.

I have here the details of one or two interesting experiments to ascertain the effects of lead placed, as is frequently done, between the joints of cut stone columns, &c., with the object of distributing the stress uniformly over the beds of the stone.* The experiments were made upon circular blocks of Bath stone, (Box Ground and bottom bed Corsham Downs), 3 ft. long by $10\frac{1}{2}$ in., and 15 in. diameter, or one set twice the area of the other; the lead being cut 2 in. less in diameter than the beds of the stones themselves. The results point to the conclusion that lead so placed between the beds of the stones, reduces the bearing strength of a column to considerably less than that of a column of only half its sectional area, in which the stones are completely bedded. On examining the sheets of lead used in the joints, they seem to have been under compression at a very few points only, and not to have in any way tended to equalise the pressure over the area of the joints. These experiments also seem to indicate that raking out the joints of cut stone work, to save the arrises in case of any compression of the joints, when bedded in mortar, should not be carried too far. Such questions are, at any rate, worth investigation.

In all experiments upon stone, it is essential to know the exact description of the stone, the quarry it came from, and if possible the particular bed in the quarry. The time the specimen has been quarried should be stated, as some stones when green will stand very little stress, but harden considerably, in a longer or shorter time, when exposed to the air. If the specific gravity, or weight per cubic foot, of the specimen were given, it would afford some clue to the state of the specimens experimented on.

While on the subject of stone, I may refer to an artificial stone, widely used in the present day, viz., concrete. I think that you will agree with me that a series of carefully made experiments on the strength of different kinds of con-

* See Pl. X.

crete would be of great value, under varying conditions, as to the nature of the lime and cement used, the description of ballast, proportion of large and small stuff, and mode of mixing.

With good Portland cement, well burnt and well ground, I should use with confidence for ordinary foundations, twelve ballast to one cement, provided I was sure of its being properly mixed; but with ordinary workmen, not properly drilled in mixing the materials, ten to one would probably be more advisable. It would be well to know how much the strength of concrete is affected by the different methods of mixing in vogue. For my own part I should insist upon the mixing being performed as follows :—A yard measure to be half filled with ballast, then the measure of cement to be added, and the yard measure filled up to the top with ballast. On removing the measure, the ingredients get partly mixed, and the cement does not get blown about so much as when placed at the top of the heap ; it should then be turned over twice dry, and shovelled into a third heap, each shovelful being sprinkled from the fine rose of a watering can as it is thrown on the heap, whence it may then be removed to the trenches. The block before you has been broken with a pick out of a newly built dock wall, in which 12 to 1 Portland cement concrete, mixed in the manner described, was employed, and I think it is strong enough for any foundations. In making experiments, the mixing should be done in bulk, at least half-a-yard cube being mixed at a time, and not in small quantities, which are more carefully prepared than would be the case in practice ; and the blocks should be at least 12-in. cubes.

Passing from concrete to mortars, the results of some experiments made for the Patent Selenitic Mortar Company, show that in mortar made with common stone lime—Burham or grey chalk lime, similar to Dorking lime, was used—3 sand makes a stronger mortar than only 2 sand, and stronger again than 4 sand, which is probably due to 3 to 1 being about the point at which more sand would weaken the cohesive and adhesive properties of the mortar to a greater extent than its setting or hardening would be promoted by increasing its porosity. With selenitic mortar, 5 sand was the best mixture to resist thrust, then 4, then 6 sand; but for adhesion and to resist tensile stress, 4, and then 6, and then 5 sand. From which we gather that 3 to 1 is the best proportion of sand to stone lime in common mortar, and 6 to 1 in selenitic mortar, since the latter gives a mortar possessing double the strength of common stone lime mortar. However, in using lately the selenitic mortar at Chatham, 6 to 1 was not found to give such good practical results as 4 and 5 to 1, which is being now used. Although the 6 to 1 mortar set very hard, it was so short that it took longer to work, the loss of time outweighing the saving of sand. The proportions now being used are 4 to 1 for exterior work, and 5 to 1 in the body of the walls. Mr. Street has, I believe, had some further experiments made with the selenitic mortar in connection with the New Law Courts.

Having said thus much with regard to the present state of our knowledge of building materials, I pass on now to the concluding part of my subject, namely, the best means of adding to our knowledge, and placing it on a firm and unassailable basis.

Now I think it will be admitted that, in a matter so important to all as the possession of accurate information with regard to the strength and properties of building materials, all who have it in their power should do their utmost to further the carrying out of a carefully conducted series of experiments on an exhaustive scale, in order, if possible, once and for ever, to clear away all doubts and doubtful theories.

It was because I felt that the members of this Institute were, above all others, most deeply interested in the prosecution of such experiments, because I knew how much depended on their united action in this matter, and that were they each and all to assist, the whole question would soon be put upon a very different footing, that I undertook to read this paper here to-night.

Means for carrying out a complete series of experiments are placed within our reach, and of a description which I firmly believe leaves nothing to be desired.

Having often had occasion to visit Mr. Kirkaldy's Testing Works at Southwark, I have been struck with the immense advantage which a public—I might almost say a national—testing apparatus, open to all, such as he has provided, has over all private efforts, however numerous.

I am perfectly aware that attempts have been made to detract from the merits of the machine designed and erected by Mr. Kirkaldy. Prejudice and self-interest are always to be found arrayed against anything new, however successful it may be; in addition to which a certain amount of opposition is always to be expected from the machine refusing to give results consistent with the theories or interests of those who are consulting the oracle.

Different experimenters, with different objects in view, different modes of conducting and recording the experiments, different kinds of apparatus employed, often unscientifically constructed and erring in opposite directions, must perforce, give different results, especially when recorded facts are read by the light of preconceived theories.

On the other hand, we have a single observer of facts, with a life-long training to the work, systematically recording the results given by a machine of most perfect construction, capable of testing materials in large masses, far beyond anything previously attempted.

Such an experimenter, who has made it the study of his life, is far more capable of recording and comparing facts with accuracy than one who has had no previous experience at such work. A comparison of the results obtained by different experimenters with the same machine even, is generally a hopeless task, from the absence of any uniform system of recording facts or conditions, such as the temperature, dryness, or exact nature of the specimen; if wood, from what part of the tree, and where grown; if iron, the alteration in form, &c.; if stone, the quarry, part of quarry, time since quarrying, &c.

I look upon Mr. Kirkaldy, silently but powerfully working day by day in a special field of knowledge, collecting and comparing facts, as one of the great levers always at work to assist the progress of scientific knowledge. It is by men like him that the world at large is constantly being benefited—though too often without acknowledging their benefactors—by men who, perceiving a great want and the means of supplying it, devote the whole of their energies to proving the truth of the ideas they are impressed with, and persevere in working them out to a successful issue.

If all the members of this Institute, especially those who have large works on hand, were to cause but a few experiments to be made, in a short time numberless facts would be collected and compared, and the range of our knowledge of building materials would be rapidly extended.

The question naturally arises, who is to pay for the experiments suggested—the builder, the architect, or his client? The answer is, neither of the three, but the manufacturer or producer of the material. For instance, let us take stone. On any large work being projected, stone merchants and quarry owners, without number, press the rival claims of their different stones upon the architect. Well, let all who wish to supply the material for the work send in specimens to Mr. Kirkaldy's works, say three 6 in. cubes, three blocks 6 in. by 6 in. by 12 in., and three 6 in. by 6 in. by 18 in. Here you have the material at once to make experiments on, the cost of which would be defrayed by the successful competitor. Of course, in the case of stone, the selection would not depend solely upon the results of experiments on the strength of the material, since its weathering properties, &c., would have also to be considered. It may be said that only well seasoned and prepared blocks would be submitted. This could either be met by the architect employing some one at the quarry to select the stones out of which to cut the specimens, or by seeing that the stone supplied came up to the standard of the specimens submitted for testing. Such a system as this could be applied to all classes of materials, and the cost of the experiments would fall on the proper shoulders. It might possibly be as well if a committee of this Institute were to lay down, in consultation with Mr. Kirkaldy, the information which ought, in each kind of material, to be recorded; and if they were, as far as possible, to circulate amongst the members instructions with regard to the number and sizes most desirable for the specimens of various kinds of materials to be experimented upon. If some such course as that suggested were acted upon by all the members of this Institute, and by Civil Engineers as well, before long a vast number of experiments would place all disputed points beyond the regions of doubt and uncertainty, we should hear of fewer failures, and avoid endless little troubles which are never heard of as failures, though in strictness they should be so classed, just as much as those which lead to serious results.

In conclusion, I can only say that if seeing assists believing, any gentlemen who take an interest in the subject I have been dealing with this evening, and who have not seen Mr. Kirkaldy's testing apparatus, would, I am sure, be amply repaid by a morning or afternoon spent in watching it doing its work; and I feel convinced that they will come away, unless they have a rival machine of their own, satisfied that it is capable of supplying with accuracy all the information they are likely to ask for. As I have already stated, one of the most important points to my mind is, as it were, the public character of the

Results of Experiments to ascertain the resistance to a gradually increased Thrusting Stress of a Log of White Riga Fir and one of Red Dantzic Fir. Length exactly 20 feet, ends cut square.

Scantling White, end 13·5 × 13·0 Centre 13·0 × 13·0 = 169 sq: in Area end 12·8 × 13·0 Red end 13·5 × 13·0, Centre 13·5 × 13·2 = 178 sq: in Area - end 13·5 × 12·5.

Total Stress in lbs: Depression inch.

Test Nº	Description.	20,000.	30,	40,	50,	60,	70,	80,	90,	100,000.	110,	120,	130,	140,	150,000.
A 1349	"White Riga"	·032	·058	·083	·103	·122	·140	·158	·176	·194	·210	·225	·240	·258	·273
	Set									·010					·014
	Deflection horizontally									·34					·41
	Dº vertically									0					0
1350	"Red Dantzic"	·035	·062	·088	·111	·133	·150	·170	·188	·203	·220	·232	·250	·263	·276
	Set														
	Deflection horizontally									·08					
	Dº vertically									·10					

Test Nº	160,	170,	180,	190,	200,000.	210,	220,	230,	240,	250,000.	260,	270,	280,	290,	330,000.	310,	320,	330,000.	Ultimate Stress. Total lbs / Total Tons	Ultimate Stress. lbs: pr sq: inch / Tons pr sq: foot.
A 1349	·292	·307	·324	·340	·358	·371	·388	·403	·420	·434	·455	·473	·492	·508	·523	·540	·565	·642	331,260 lbs	1,960 lbs
Set					·016										·022				147·88 Tons	126·04 Tons
Deflection horizontally					·47					·53					·64					
Dº vertically					0					0					0					
1350	·292	·302	·318	·329	·346	·354	·370	·384	·400	·414	·440	·469	·488	·507	·548	- - -	- - -	- - -	309,120 lbs	1,742 lbs
Set					·020										·033				138·00 Tons	112·02 Tons
Deflection horizontally					·19					·25					·47 08					
Dº vertically					·22					·29					·55 11					

A 1349 Gave way at knots 2'·9" off centre; 1350 at knots 0'·9"

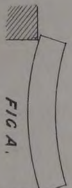


FIG A.

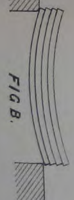
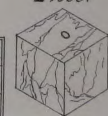


FIG B.

Results of Experiments to ascertain the resistance to Thrusting Stress of six cubes of Red Sandstone.

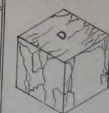
Test Nº	Quarry	Dimensions H . L . B.	Base Area.	Cracked slightly. Stress	pr sq: in:	pr sq: foot.	Crushed, Steelyard dropped. Stress	pr sq: in:	pr sq: foot.
E		Inches.	Square ins:	lbs	lbs	Tons	lbs	lbs	Tons.
1892.	"O" Ormside	5·98. 5·95 × 5·93.	35·28.	85,270	2416	155·4	118,160	3349	215·3
1891.	"O" dº	5·95. 5·95 × 6·00.	35·70.	84,120	2356	151·5	117,720	3298	212·1
1893.	"O" dº	12·00. 11·96 × 12·02.	143·76.	346,620	2411	155·1	443,930	3088	198·6
				Mean	2394	154·0	Mean	3245	208·6
1895	"D" Dufton	5·94. 6·00 × 5·98.	35·88.	83,520	2328	149·7	93,870	2617	168·3
1894	"D" dº	5·90. 5·94 × 6·00.	35·64.	81,270	2280	146·6	92,580	2599	167·1
1896	"D" dº	12·00. 12·00 × 11·90.	142·80.	323,880	2268	145·9	358,230	2509	161·3
				Mean	2292	147·4	Mean	2575	165·6

E 1893.



Bedded with pine quarter inch thick

E 1896.



Bedded with pine quarter inch thick

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David Kirkaldy.

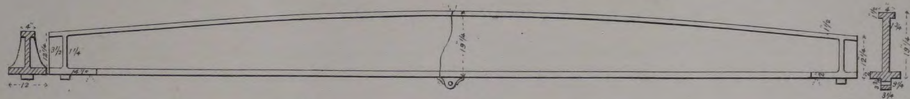
PL. VII.

Results of Experiments to ascertain the resistance to Deflection Set and Rupture under a gradually increased Bending Stress of one Cast Iron Girder.

Distance between Supports 18′ 0″ Length of Girder 20′ 5″ Weight of Girder 1. 7. 3. 14 lbs:

	5 Tons 11,200 lbs:	10. 22,400.	15. 33,600.	20. 44,800.	25. 56,000.	30. 67,200.	35. 78;400.	40. 89,600.	45. 100,800	45·19 Tons 101,240 lbs } Broke
Deflection, inch.	·048.	·172.	·296.	·418.	·558.	·677.	·828.	·980.	1·17.	1·18 inch.
Set, inch.					·046.		·087.			

Girder marked A. Test number D 560. Tested 21st April 1869.

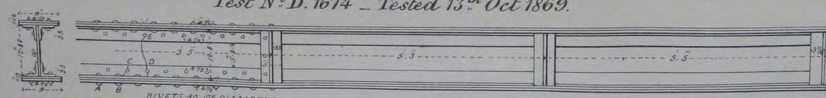


Results of Experiments to ascertain the Resistance to Deflection Set and Rupture under a gradually increased Bending Stress of one Wrought Iron Girder.

Distance between Supports 23′ 2″. Camber 0·55 inch. Length of Girder 26′ 6″. Weight 1. 13. 3. 21 lbs:

Stress in lbs:	20,000	25.	30.	35.	40.	45.	50.	55.	60.	65.	70.	75.	80.	85.	90.	95.	98,790 lbs: or 44·1 Tons:
Deflection, inch	·212.	·331.	·462.	·598.	·739.	·883.	1·03.	1·19.	1·34.	1·50.	1·68.	1·87.	2·08.	2·34.	2·74.	3·46.	4·59 inches 1st plate snapped at A.
Set, inch.			·091.		·186.		0·29.		0·43.		0·58.		0·80.		1·31.		5·25 do. 2nd do. & angle broke at B.C. 6·20 do. Web plate & Angle D.E.

Test No. D. 1674 _ Tested 13th Oct 1869.



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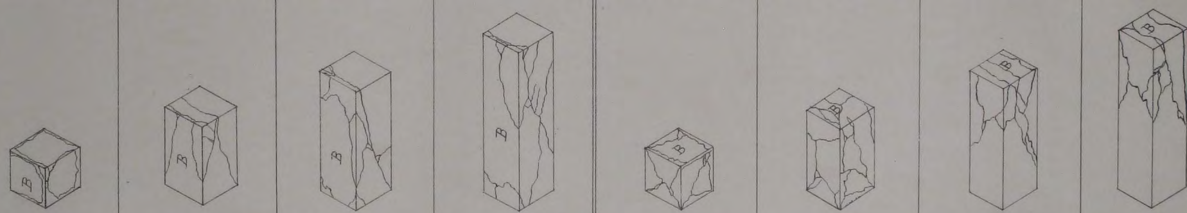
PL. VIII.

Results of Experiments to ascertain the resistance to a gradually increased Thrusting Stress of eight pieces of Doulting Stone from Charles Trask's Quarries Shepton Mallet, Somerset.

Tested "Against" the Bed				*Tested "On" the Bed.*			
F.1674.	**F.1675.**	**F.1676.**	**F.1677.**	**F.1739.**	**F.1740.**	**F.1741.**	**F.1742.**
6·04×6·05=36·54 super: height 6 inches.	6·04×6·02=36·36 super height 12 inches.	6·03×6·02=36·30 super: height 18 inches.	5·98×6·00=35·88 super: height 24 inches.	5·98×6·00=35·88 super: height 6 inches.	6·07×6·08=36·91 super: height 12 inches.	6·08×6·04=36·72 super: height 18 inches.	6·04×6·06-36·60 super height 24 inches.



Cracked slightly with 75,240 lbs. or 2097 lbs. per square inch.			Cracked slightly with 62,270 lbs: or 1735 lbs: per square inch.		Cracked slightly with 69,240 lbs: or 1876 lbs: per square inch.	Cracked slightly with 72,770 lbs: or 1982 lbs: per square inch.	
Crushed 89,180 lbs: or 2441 lbs: per square inch.	Crushed 79,620 lbs: or 2189 lbs: per square inch.	Crushed 70,870 lbs: or 1952 lbs: per square inch.	Crushed 65,890 lbs: or 1836 lbs: per square inch.	Crushed 89,380 lbs: or 2490 lbs: per square inch.	Crushed 83,620 lbs: or 2265 lbs: per square inch.	Crushed 79,850 lbs: or 2174 lbs: per square inch.	Crushed 77,040 lbs: or 2105 lbs per square inch.

All bedded with Pine quarter inch thick.

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PL. IX.

Results of Experiments to ascertain the resistance to a gradually increased Thrusting Stress of four Columns of Bath Stone.

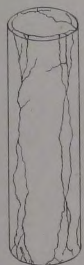
"Box Ground"

E 577.

Diameter 10·41 / 10·73 } 10·57 inches.

Area 87·70 square inches

Length 35·06 inches.

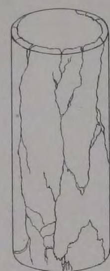


E 578

14·97 / 15·03 } 15·00 inches

Area 176·71 square inches

Length 34·52 inches.



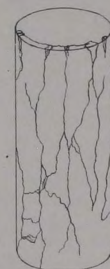
"Bottom Bed Corsham."

E 579.

Diameter 14·94 / 14·98 } 14·96

Area 175·68 square inches

Length 34·92 inches

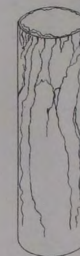


E 580.

10·55 / 10·59 } 10·57 inches

Area 87·70 square inches

Length 34·92 inches.



Bedded with four lbs: Sheet Lead cut 2 inches less diameter than Column according to instructions

E 577. 61,730 lbs: or 27·5 tons = 704 lbs p: sq: in:

Cracked at both ends of Column and very rapidly extended the whole length, part of lead at one end not marked.

1088 lbs: per sq: inch of lead area.

E 578. 10,680 lbs: 570 lbs p: sq: in:
very slightly cracked

143,950 lbs: 64·25 tons = 815 lbs p: sq: in:
Cracked in all directions.
Lead at both ends uniformly marked.

1084 lbs: per sq: inch of lead area.

E 579. 97,920 lbs: 43·71 tons = 556 lbs p: sq: inch.
Very slightly cracked.

120,730 lbs: 53·90 tons = 687 lbs p: sq: inch:
Only one half of circumference cracked.
Markings on lead prove that the ends had not been formed quite true.

E 580. Bedded with Pine quarter inch thick cut to same diameter as Column as always recommended by me.

122,280 lbs: 54·60 tons = 1394 lbs p: sq: inch
Very slightly cracked at one end.

130,810 lbs: 58·39 tons = 1492 lbs p: sq: inch
One end uniformly cracked all round, the other end but slightly.

These two experiments reveal the startling and important fact that a column properly bedded is very considerably stronger than one of double the area improperly bedded.

Testing and Experimenting Works.

The Grove, Southwark Street,
London. S.E.

David Kirkaldy.

PL. X.

work, open to all comers and all materials, and containing complete and accurate records of experiments made with no aim or object but that of truthfully recording facts. I think that such an institution ought hardly to be left to the unaided enterprise of a single individual. I look upon its success as a matter of national importance, greatly affecting the safety as well as the pockets of the public at large, whether sitting in their houses, whirling along on railroads, or crossing the seas in ships. Numberless lives are year after year lost, life-long miseries caused, and thousands upon thousands of pounds wasted, from a want of proper knowledge of the strength and properties of building materials.

PAPER III.

THE ENGINEER ATTACK UPON LARGE FORTRESSES.

Translated from the "Militair Wochenblatt," for April, 1873,

By Captain F. C. H. CLARKE, R.A.

In spite of the abundant experience in fortress warfare, during the last campaign, our knowledge is deficient on the main question, viz., the formal attack on large places of arms, like Paris. Strasburg was an antiquated fortress, and the operations before Metz and Paris were limited to mere investments; the siege of Belfort was the nearest approach to an attack on a modern fortress, but the forts were constructed on far too small a radius to present any grave difficulties.

It is our intention, in this paper, to take Prince Hohenlohe Ingelfingen's brochure "On Sieges"* as our basis, and deduce principles for the formal siege of a large place of arms, like Paris; assuming that the infantry, on both sides, are armed with a long-range breech-loader, that the artillery of the besieger is entirely, and that of the defender sufficiently, provided with rifled cannon and heavy mortars.

Every formal siege being preceded by an investment lasting for some weeks, if not months, we will commence with this part of the proceedings.

The first and most important matter, when an army prepares for the invest-

* See Royal Engineers' Professional Papers, Vol. xxi., p. 90.

ment of a large place of arms, is to fix the *position of the advanced picquets (Feld-wachen.)* This will be arranged by the commander-in-chief, in concert with the commanding engineer, so as to exclude the possibility of any error, or misunderstanding, and thereby avoid the construction of any unnecessary works. This appears the more important, as it is during the early days of the investment, when the positions of the outposts, in front of the fortress, are unknown to us, and when the works of fortification cannot have progressed very far, that sorties of the defenders are most dangerous.

The besieger must have two fortified positions, one in rear of the other.

(1) The *position of the advanced picquets*, and (2) the position upon which the picquets fall back for support, the *supporting position*, each of which must be defended with energy. If circumstances permit of the advanced picquets remaining in their position, the main body will support them in this advanced line. This will always be practicable, if the sortie takes place by day, and we are not taken unawares.

The distance of the *position of the advanced picquets*, from the outer line of the permanent works of the fortress, may be assumed at 4000 to 5000 paces, that of the *supporting position*, at 6000 to 7500 paces. Four and six thousand may be considered the minimum for each position, respectively, when we are opposed to a formidable array of breech-loading guns.

Should it be necessary to fortify villages, woods, and such like, which are in close proximity to the forts, it must be done with care, and in a substantial manner.

The *position of the advanced picquets* must be the first, and the most carefully, strengthened, so as to enable infantry, posted there, to hold out to the last. The first points for consideration, are the best positions for the artillery, proper cover for the men, with good covered communications, both laterally, and to the rear; obstacles are of secondary moment. The *position of the advanced picquets* must be always strongly occupied; infantry, when retiring under fire of breech-loaders, suffer too great a loss for us to require them to occupy a position merely for the purpose of watching the enemy, or even to hold it until the sortie party has deployed superior forces. Should the outposts then have to fall back, they impede the fire from the main position. Instructions, to fall back upon the main position before superior forces, have always proved impracticable, for the reason, that, at the commencement of the action, this superiority of force is not developed, neither can it be seen, in the event of fog, or by night; moreover, a well defended position is tenable against a three-fold superiority of force; and, lastly, every commander of outposts has to avoid unnecessarily alarming the resting troops. On the other hand, the order to hold out, under all circumstances, is simple and clear, and ensures correct dispositions; it is only necessary that the *position of the advanced picquets* be strongly occupied, *i.e.*, with about one-fourth of the infantry.

The *supporting position* must always be occupied from the first, and be sooner reached from the cantonments of the investing troops, than by the force making the sortie. The villages, within this position, should be used for quartering the infantry and engineers, while the artillery, cavalry, and train are encamped further to the rear.

In protracted investments, the quartering of troops, within range of the guns of the fortress, is not devoid of danger, and would be impossible, in the event of the houses, &c., not being solidly constructed, or if the forts be armed with a number of heavy guns. If, on the other hand, the formal attack follows closely upon the investment, the bombardment of the cantonments ceases directly the first batteries have opened fire on the forts.

Owing to the few large places of arms, it will be possible, in time of peace, to deliberate upon all the questions raised here, and make known the necessary arrangements, when advancing towards the fortress.

In—or better still, in rear of—the *supporting position* is placed the artillery, mounted in *emplacements* on all the commanding positions, with their limbers properly protected, ready to fire over the heads of the *position of the advanced picquets* against the sortie.

Field guns are best placed at distances of 20 or 25 paces apart; and these distances should not be altered when there is a parapet in front. If placed at five paces apart, one large shell would place the whole battery *hors de combat.*

There is no hurry for tracing out the parapets to protect the guns and limbers; it is quite sufficient at first to select the sites for the batteries, to lay the platforms, and make such roads from the artillery cantonments to the emplacements, as will not be rendered impassable by heavy rain. After completing the cover for the infantry in both positions, we may then proceed with providing the guns and limbers with cover. As these earthworks on commanding positions will be visible to the defender on the first clear day, he will direct his sorties and his guns upon them.

Isolated or advanced points, such as chateaux, farms, and especially entrenchments, even if strengthened with the resources of field fortification, are useless against the heavy rifled artillery of the present day; as the field artillery of the investing force cannot cope with this latter, it can calmly cannonade these points and compel their evacuation. In consequence of the destructive effect of modern artillery and small arms, the *lines* in both positions should be *continued,* but permitting of a debouch at all times. The best method of defending such lines is not to show a man until the sortie is close up to them, and then to rush to the banquettes and commence file firing.

The lines will be made up of shelter-trenches, loopholed walls, hedges, ditches, and borders of woods.

The description of shelter-trench which is most to be recommended, is that with a full profile, giving cover equal to a man's height. The half sunken description should be used less frequently, as it seldom permits a good view over the ground in front, and the presence of vineyards, beans, peas, asparagus, or artichokes, renders it inapplicable. Moreover the full profile, where the berm also forms the banquette, has the advantage that the defenders cannot be seen from the outside, that they are in a more commanding position, that cavalry get a slight amount of cover behind it, and that barracks can be built inside. For the latter reason, a certain part of the shelter-trenches should be traced with a full profile, even when as regards the effect of fire the half sunken would suffice, as in protracted investments extending for weeks and months the infantry will be desirous of housing their advanced picquets in barracks. Steps in the reverse slopes are not to be recommended, as no earth will stand the wear for a long time. On the other hand, a gentle ramp permits officers and orderlies to ride in and out with ease.

Walls should be provided on the inner side with banquette steps of earth, which should be covered with planks. With these steps and the ditch which supplies the earth from them, a description of shelter-trench and cover is formed, should the enemy, as a preliminary to a sortie, cannonade the wall and bring down parts of it with his heavy guns. If there be plenty of time and material, it will be advantageous to lay sand-bags or sods on the top of the walls, so as to render the splinters of stone less dangerous.

Hedges should also be strengthened with earth on the inner side, and provided with steps covered with planks to form a banquette.

Scaffoldings may be used behind walls, in buildings, &c., in the early part of the investment, or for an action, but they should be replaced, as soon as possible, by earth.

As outposts are always on the look-out for wood and furniture, for fires, and to make themselves comfortable, these wood constructions are apt to disappear as rapidly as they are put up. Before Paris, defensive arrangements of this nature at an important point, disappeared altogether after some weeks. We would observe, as a general rule, (and this is an evil against which precautions must be taken,) that our men at the advanced picquets did hardly anything for the improvement and maintenance of their defensive arrangements or barracks; but on the contrary, spoiled and destroyed what had been done. Nobody lifted a hand to deepen a shelter-trench into which the enemy could see; but the reliefs preferred a hundred times over to crouch down when passing it on their rounds. Hence, abattis, palisades, barricades, and scaffoldings are always in danger of finding their way into the watch fire.

It is not advisable to occupy and fortify isolated buildings, even when of large extent and solidly built, if within range of the artillery from the fortress. It is, on the contrary, better for the commander-in-chief to forbid the defence of isolated buildings, as the defenders are liable, in a rearward movement, to be cut off and taken prisoners. In the event of a building of this sort being unfavourably situated for defence, it should either be demolished, *i.e.*, levelled to the ground, or at any rate, all the staircases should be removed, and the walls of the house broken down on the side turned towards us.

Should there be a conspicuous building which offers a good mark for the fortress artillery to get the range, it will generally suffice to paint it black.

All walls, hedges, and fences in the gorges of villages within the lines, should be levelled, the ditches filled up, &c., so that in the event of the village being lost, which may happen at night, in foggy weather, or from the great preponderance of the sortie party, its recapture may be facilitated, and the unavoidably heavy losses diminished.

The levelling of garden walls in front of Paris was not found such a heavy task as was anticipated. They could generally be overturned quite close to the ground by means of a battering ram, such as a ladder, a trunk of a tree, or similar contrivance.

Obstacles should only be placed in front of the *position of the advanced picquets*, and even then only at exposed places. Their precise position and nature must be imparted to the men, so as to avoid mistakes and losses in action.

In clearing the field of view, material is obtained for abattis, but these can seldom be regarded as an obstacle of a formidable nature. Their effect may be increased by strong iron wire, connecting one tree or one branch with another. These wire abattis have been much used. Where there is no wood, wire entanglements are the best, as they are very effective, and do not impede the fire. The French used them constantly.

Advanced picquets which are posted in the open, or have some definite point to hold, which must not be abandoned under any circumstances, should, in the absence of any cellars, grottoes, or other subterranean works, be provided with the so called shell-trenches to creep into during a heavy shell or shrapnel fire. These are about 5 ft. deep, and about the same breadth at the bottom, the men getting cover behind this increased depth of earth. The length will depend on the strength of the advanced picquet. At each end there should be a ramp, so as to permit of the banquettes being rapidly lined in the event of a sortie. These shell-trenches should be constructed in a position which will give as much cover as possible; consequently, they are not to be arranged for defence, but all the slopes are to be kept as straight as possible, and, if necessary, they should be covered with planks, for protection against the splinters of the shell flying to the rear. The men sit on the step, which is left at the bottom of the trench on the berm side, with their rifles between their knees. We shall never forget the French concentrating the fire from their heavy naval guns upon an advanced picquet, throwing, perhaps, 200 shells on one spot in the course of one or two hours.

In the line of investment round Paris, we may cite the position of the 7th Division as a model. The *position of the advanced picquets* was 4,000 paces, the *supporting position* between 5,000 and 6,000 paces, distant from the northern forts. Both lines were continuous; roads and paths were only closed with barricades, which overlapped like traverses, and permitted carriages to pass through in a snake-like manner.

The *position of the advanced picquets* had, as points of support, the parks and buildings at Ormesson, the village of La Barre, the park and chateau of Chevrette, and the front walls of the vineyards at the village of Deuil; from this latter, a shelter-trench led to No. 7 advanced picquet, which was in the open, under four large nut trees. The aforesaid villages were connected together with shelter trenches.

The *supporting position* consisted of the fortified borders of the villages of Enghien and Deuil, which were also connected by means of a shelter-trench.

In rear of this supporting position there were thrown up, on the hill in front of Montmorency, emplacements and limber-pits for 24 guns which swept all the ground up to the forts, and took in flank the most exposed part of the supporting position.

The town of Montmorency, which is situated on an elevated position and surrounded with the remains of a mediæval wall, was fortified as a *réduit* to the position.

To return to our subject.

During the works of investment, the front of attack has been selected, the main features of the plan of attack decided upon, and the siege companies (artillery and pioneers) and the artillery and engineer parks are in process of formation. The choice of the front of attack is so much influenced by the position of the railway, which should if possible carry the material to the parks, both in an artillery and an engineer point of view, that only the most cogent reasons can justify the selection of another front. Of this, the experience of the last war leaves no doubt.

The pioneer companies for the formal attack are formed into battalions. They are, with regard to their disposition, rationing, quartering, and requisitions for working parties, attached to a Division of the corps undertaking the siege. They are told off for good to some special section of the attack, each forming its own engineer park (brushwood, tools, and artificers' store depots); the brushwood depot should be as far forward as possible, so as to avoid unnecessary transport. The preparation of brushwood should be arranged by companies in the cantonments of the pioneers, the infantry quartered in the immediate vicinity assisting with a working party. The formation of a single large engineer park, as was formerly the case, is now forbidden by the distances to which material would have to be carried, and by the unavoidable crossings with the columns of workmen. On the contrary, it is desirable that the different pioneer companies should, in addition to the battalion parks, form minor tool and store depots in their cantonments.

The distribution of the pioneers should be so arranged that each company is encamped in rear of the section of attack to which it is appointed, so as to avoid any loss of time in the reliefs of workmen going to their duties, and in the transport of materials.

We must now consider the works for the first artillery position, to which the position of the advanced picquets forms a screen.

When the batteries are being thrown up and armed, the pioneers will be employed in opening up the communications, in forming the roads for the columns to the batteries and between the batteries, and also in making any alterations in the tracing of the front line of investment, for the better protection of the batteries of attack.

The fire from the first artillery position, combined with the forward pressure of the infantry, drives the defender back into his works; the advanced picquets take up a position within about 1,000 paces from the forts and entrench themselves there.

We have now to deal with the opening of the 1st parallel and the formal attack by sap. The general scheme upon which the engineer attack of the present day is based, is, in its main features, the same as in Vauban's time, in spite of the improvements in effect, range, and accuracy of rifled guns and firearms, and irrespective of the radius of the works of defence being greatly extended, and of the changes which the art of fortification has undergone in the space of 180 years.

These changes partly facilitate and partly increase the difficulties of siege warfare.

The changes *in favour* of the engineer attack are—

(1.) The batteries can be placed at so great a distance, that the first parallel can be thrown up under the protection of their fire, and, therefore, the operation is not so dangerous as formerly.

(2.) The formation of the so-called "second batteries" (breaching and counter batteries at the crowning) will only be exceptionally necessary, and, therefore, the number of zigzags of approach is reduced to a minimum.

(3.) The parallels being, as a rule, only intended for infantry, it does not appear any longer necessary to have a complete communication throughout from one flank to the other.

(4.) The great range of modern arms permits of a greater distance between the parallels. If, in Vauban's time, the smooth bore, with a point blank range of 100 yards, permitted the parallels to be constructed from 400 to 500 yards apart, then, with a present point blank range of 400 yards from the rifled arm, a distance of 800 to 1,000 yards is certainly permissible. It may therefore be said that the second and third parallels are only necessary to supplement or increase the effect of the fire from the first parallel. They consequently come more under the category of what is understood by demi-parallels.

(5.) A front attack by the defender has no probability of success in these days of rapid fire; the losses attending a withdrawal do not compensate for the results which possibly might be gained.

(6.) The bodies of men, which the besieger has at his disposal in the present day, enable any extra work to be done, which may be entailed in throwing up saps of considerable profile and moving large masses of earth.

On the other hand the changes affect the engineer attack *unfavourably*, as follows:—

(1.) The determined maintenance by the defender of the ground in front of the fortress to a distance of perhaps 1,500 yards, and the watchfulness of his outposts, offer serious impediments to reconnoitring the works.

(2.) Even the laying out of the first parallel at 1,000 paces will have to be effected within range of musketry, and in the case of forming a second parallel and the approaches, the difficulty is immensely increased, as the effect of fire n the present day against columns is very considerable.

(3.) The nearly parallel front occupied by the besieger, with reference to the defender, renders it very difficult to defilade the zigzags, even from the first to the second parallel. It will be comparatively easy for the defender to enfilade them along their whole length by forming counter-approaches, and to compel the besieger to throw up traverses in the zizags. These difficulties will increase at every step; even if the line of forts be reached, an approach by zigzag against the enceinte from thence may be set down as perfectly impossible under all circumstances. Let us call to mind the condition of affairs at the northern and southern attacks on Paris, when the right flank of the first parallel of the former rested on the Seine, and was taken in flank from the French fortifications on the peninsula of Genevilliers; in the same manner the 1st parallel of the southern attack was seen into from both sides, on the left from Billancourt, on the right from the strong position at Cachan and Haute Bruyère. Upon what point, might we ask, would the first zigzag have been directed, had it been requisite to proceed from the captured line of forts against the enceinte of the city?

(4.) As the defender has to give up his front sorties, he will naturally commence strong sorties upon the flanks of the parallels and batteries.

The system which has obtained hitherto, is almost useless. Approaches and communications are not adapted for defence; the defender of the parallels will be rolled up and taken in reverse. The further the sapping is advanced, the more dangerous and more effective do these flank attacks become, and the more imperative does it appear to adopt counter-measures.

(5.) Curved fire at long ranges renders the protection of saps by traverses, which are not higher than the sap parapet, an illusion. The saps are only protected from view, not from fire.

(6.) The space to be traversed by sapping is immense, and necessitates the greatest economy in time. Works selected for attack must therefore be approached along the shortest line.

(7.) While formerly it might be assumed with confidence that in the last stages of sap-attack the effect of the defender's artillery would be feeble, yet in the present day, with the difficult tasks of the crowning-sap, the descent, the lodgment, &c., in front of and in the forts, the besieger will be received by a vigorous fire from the batteries in rear, either in the open or from the enceinte. For this tremendous fire the fort immediately attacked plays the part of an observatory. It therefore appears desirable to construct the blinded sap *(bedekte sappe)*, and the gallery of descent more solidly, as large shells impinging at angles of descent varying from 15 to 20 deg., will penetrate more deeply and be more effective than the old mortar shells which fell almost vertically.

The experiences of the last war have, we repeat, not shewn that modifications in the formal attack have become an absolute necessity, but, it will be generally acknowledged, that even the preliminaries to a siege of Paris have demonstrated that the scheme of attack hitherto in force is not adequate.

It is, therefore, recommended, in consequence of what we have adduced:—

(I.) That the first parallel should be thrown up at 1,000 paces distant from the forts, after the artillery has previously paved the way. The formation of this main infantry position at the outset, as laid down in the regulations, will, as a rule, be impossible. The fortified positions already occupied by our advanced posts may be connected together with trenches.

(II.) That the advance upon the capitals of works should be made in a straight line from the first parallel, at first by flying sap, and afterwards under cover of cylinders filled with earth. Traverses 20 feet thick, and 3 feet higher than the crest of the parapet of the approaches, may be built as required; beforehand, if the flying sap is used, and afterwards, in the case of the cylinder. The men working at the head of the sap, upon whose progress everything depends, will therefore push forward along the shortest line to the work attacked, as there will be ample time and means to extend and complete the works afterwards. By so doing, time is saved; even with the single sap we ought to reach the crest of the glacis in four weeks. The sappers work straight along the capital, so as to use the attacked work as a cover against the batteries in rear, as it may be assumed that the direct fire of a fort is more easily silenced than that of the curved-fire batteries in rear or on the flank.

These direct approaches should be provided with banquette steps on both sides, and, as they must therefore be made considerably wider than has hitherto been the case, it will be well to have two parties sapping parallel to each other. The defenders of the banquette will be covered by the increased height of the traverses.

(III.) That the approaches should be pushed on without waiting for the second and third parallels being finished; the latter, on the contrary, should be carried on simultaneously, or at a subsequent period, and only so much should be constructed as is necessary for commanding the ground in front. Just as in the case of the 1st parallel, they should be made by connecting the different riflemen's posts.

(IV.) That, on reaching the glacis, the approaches are continued to both flanks either into the mine-lodgment or along the crest of the glacis into the crowning. This latter should also be provided with traverses 3 feet higher than the crest.

(V.) That, after capturing a fort or two, a new main infantry position (second parallel) should be formed, and the new objects of attack in the enceinte in their turn approached in a straight line. If the approaches come very near together, the banquette steps may be omitted.

In other respects no further changes need be introduced into the original scheme. The communications may be still made by zigzag, and the banquettes be provided with steps where required. No storming of the breach will be necessary. The attention of the defender will be mainly directed to making flank attacks, to building curved-fire batteries and counter-approaches, and above all things to subterranean warfare.

This new mode of attack on large places of arms must naturally exercise an important influence upon the whole business of the sapper. The following points will require consideration, and some of them should become subjects for the instruction and training of this branch of the service:—

(1.) Sapping by two parties working simultaneously, parallel to each other, using cylinders filled with earth. Distance between reverse slopes 10 feet to 13 feet.

(2.) Throwing up traverses 20 feet thick and 8 feet high in a flying sap.

(3.) The same in the ordinary way, with the greatest possible cover.

(4.) Constructing blinded saps and descents into the ditch more solidly than heretofore.

(5.) Discovery of some less troublesome mode of carrying on flying sap.

As regards blinded saps, we must avoid altogether the fragile wood construction in vogue hitherto. We must excavate to the height of a man, fix on the berm broad wooden balks, place iron rails over them, each of which must be firmly secured, and over the whole place timbers, fascines, and earth. The descents into the ditch must be similarly executed. Wet ditches can be best passed by means of rafts.

Flying saps are at present executed as follows:—The columns are formed in two ranks, each man carrying a gabion and intrenching tool. When the gabions are placed on the tracing line, one of the ranks give their tools to the other, and form as a covering party. The other rank works, consequently each man has two gabions to fill.

Under heavy fire, or from want of instruction or appreciation on the part of the men, it is found that both ranks come to the front, which cannot be remarked at night, and confusion becomes unavoidable. Also, as speaking in a loud tone of voice, is not permitted, it has been found necessary to keep both ranks at the gabions and let them work alternately. Many men are thereby exposed, the columns of working parties are double as long as they need be, and the losses proportionate.

Sapping shields should fulfil the following conditions:—

(1.) They should not be heavier than 40 to 50 pounds, so that they may be easily carried for long distances.

(2.) They must be of a convenient form for carrying, and easily set up.

(3.) They must cover as much length of ground as represents a working task.

(4.) They must protect a kneeling man from fire.

A shield of steel plate and wood, about 3 feet 9 inches square, would appear suitable. It should incline forwards. The French used a bullet-proof shield of this description before Paris, called the Alexandre Plastron; it weighed 50 pounds, and was made of $\frac{1}{4}$ inch steel plate. The introduction of a good shield would enable the columns of working parties to be reduced one-half, the covering party and workmen could be kept distinct, and the latter would be better covered than at present.

VON W.

PAPER IV.

USE OF THE SUSPENSION PRINCIPLE FOR MILITARY BRIDGING.

BY LIEUT. T. FRASER, R.E.

The following paper is the result of some years of practice in making different forms of military suspension bridges at the School of Military Engineering. It contains detailed accounts of the ways of making three kinds of bridges that have been found to answer, as well as the more important calculations connected with them. The formulæ used for the calculations are given, for convenience of reference, in Appendix A; while the results of certain experiments on suspension cables are stated in Appendix B.

GENERAL REMARKS.

Site. A site should be chosen with banks of the same height, and of sound rock or clay.

Materials for cables. The best materials for the cables are steel or iron wire ropes or chains, which stretch but slightly. Hemp ropes are often used. Besides these, boards nailed together, iron gabion bands, sail cloth, thongs of hide, and ropes of creepers or grass are sometimes employed. When several ropes are used instead of one large one, care must be taken to stretch them all evenly. Hemp ropes are sometimes twisted into a cable for this purpose.

Considerations as to dip. The *dip* of the cable usually varies from $\frac{1}{10}$th to $\frac{1}{15}$th. A deep curve strains the cable less, and does not require such distant anchorages; while a flat one is less liable to oscillation, but loses form more quickly from stretching. The great difficulty with a suspension roadway is the want of stiffness with a concentrated load; this being particularly the case near the piers. With high banks, ties may be taken down from the roadway, as at B, fig. 1, Pl. XI., and anchored to the bank; these help to check oscillation, and should be used when practicable; but the main point is to use long road-bearers, and long stiff ribands breaking joint with the road-bearers; or, better still, to use light lattice girders of planking, which answer both as road-bearers and stiffeners. Lateral oscillations, due to moving loads and wind, may be provided for by guys taken from the centre of the bridge and secured to land-ties ashore, as far to the right and left of the bridge as is convenient.

By carrying back the cable to E (fig. 12), the thrust down the pier becomes vertical, or nearly so; any variation from this, due to distortion of the cable, is provided for by struts and ties (fig. 16). When (owing to the nature of the banks) the anchorages cannot be carried back the proper distance (D E, fig. 12), the piers must be stayed and strutted so as to provide fully for the oblique thrust on them.

In all cases when the working parties cannot pass from bank to bank at the site of the bridge, time is saved by stretching a line across, as in fig. 26, with a block to travel on it, and take rope ends, &c. backwards and forwards.

Methods of supporting the roadways.

In suspension bridging there are three convenient ways of using the suspension cables as supports for the roadway.

The first is to lay the roadway partly on the cables and partly on balks. (Fig. 1.)

The second is to support a horizontal roadway on trestles carried by the cable. (Fig. 8.)

The third and most usual method is to hang the roadway below the cable. (Fig. 16.)

The first plan is the simplest, and requires least materials; it answers for troops and light guns.

The second provides a very stiff bridge, and saves having high piers, but is more influenced by wind, &c.

The third provides a road fit for all kinds of traffic, but requires more material than the first.

The method of laying the roadway direct on the cables from bank to bank which has to be used in gabion band bridges, should be avoided when possible, as an inspection of the curve (fig. 1), and Table, page 60, shows that its property is to be comparatively flat for one quarter the span on each side of the centre, while the portions near the piers are steep. Thus in a curve with a dip of $\frac{1}{10}$th, the slope of the curve at half way between the centre and pier is at most $\frac{1}{6}$th, gradually decreasing to nothing at the centre, while at the piers there is a slope of about $\frac{1}{3}$rd; which is too steep for guns or horses, and inconvenient for men.

Arrangements of roadway.

The roadway itself may consist—

1st—of chesses alone on the cables (centre of fig. 1.)

2nd—of chesses on balks, which are slung from the cables (figs. 1, 2, and 19,) two slings being used at the junctions of the balks, which correspond with the centres of the ribands.

3rd—of chesses, balks, and transoms (figs. 16 and 18).

The first two are only fit for light wheel traffic.

Measurement of dip.

The dip of a suspension cable, the lowest point of which is below the banks, can be regulated by nailing small straight edges to corresponding piers (chalk marks will answer instead) on each bank and at the same level. A trestle like those in fig. 8, but of light sticks, can then be hauled out to the centre of the cables. The vertical height of this trestle from transoms to ledgers should be the required amount of dip below the straight edges. The cables can now be hauled in or let out so as to bring the transoms in line with the straight edges.

When, as in fig. 16, the vertex of the curve is to be above the banks, the straight edges can be nailed at the proper height on the piers, and the cables sighted along them. In all cases, if the dip be too great, the cables may be marked at E, (fig. 5), and at A, (fig. 16), close to the pier cap ; then hauled up the required amount, as hereafter described, a fresh mark made on the cables at the pier cap, and the distance between the two marks measured. The cables are now taken in at the anchorage, till the point E (fig. 5) is brought up and secured to E_1 ; $E\,E_1$ being twice the distance between the marks at A (fig. 16), the dip will then be what is required.

Tools and Materials for Suspension Bridges.

The following list of Stores and Materials will be required for each of the three Suspension Bridges hereafter described, in addition to those special to each :—

DESCRIPTION.	Number or Quantity for the		
	100 Feet.	130 Feet.	200 Feet.
STORES.			
Augers, bottle-nosed ½ in., for dogs	2	2	2
Ditto do. do. 2 in., (pocket) for trenails	1	1	1
Axes, felling, c. p., helved	1	1	1
Axes, pick, 5 lbs.	8	8	16
Blocks, double and treble, pairs of, with 3 in. (white) rope	2	2	2
Blocks, snatch, 8 in., (for 3 in. rope)	1	3	5
Dogs, iron, ⅝ in. round, 12 in., with 6 in. spikes	56	64	32
Files, saw, 3 square { hand	1	1	1
Files, saw, 3 square { cross cut	1	1	1
Handspikes, 6 ft.	2	2	4
Levels, Field service	1	1	1
Mauls	2	2	2
Pickets, Park (3 in.) 5 ft.	4	4	4
Plyers, pairs (if wire racking be used)	2	2	2
Rods, 6 ft.	2	2	2
Saw, cross cut, 5 ft.	1	1	1
Saw, hand, 26 in.	1	1	1
Sets, saw { hand	1	1	1
Sets, saw { cross cut	1	1	1
Shovels, universal, helved	8	8	16
Tapes, measuring	2	2	2
MATERIALS.			
Cables, Pontoon, (3 in.) 30 fathoms long	4 to 8	4 to 8	4 to 8
Cable Seizings of Yarn (strong) 3 fathoms each	12	12	16
Chalk, Pieces	4	4	4
Fascines, 18 ft. by 9 in.	10	10	12
Grease, lbs., for bearings and saws	2	4	4
Lashings, 2 in., 8 fathoms each	4	9	12
Lashings, 1½ in., 5 fathoms each	12	104	10
Lashings, 1 in., 3 fathoms each	30	280	100
Lines, Hambro'	1	1	2
Pickets, Bundles of	2	4	2
Planks, 7 ft. 6 in. by 12 in.	100 (2 in.)	130 (1½ in.)	200 (1½ in.)
Plates, iron (bent), 3 ft. by 3 in. by ¼ in.	...	4	4
Racksticks or Wedges	0	84	100
Selvagees, spun yarn	5	5	36
Spikes, iron, 9 in.	20	32	8
Spikes, iron, 6 in.	0	8	12
Tapes, tracing	2	3	2
Thread Pack, balls	1	1	1
Trenails, oak (2 in.), 12 in. long	8	8	8
Wire, iron (14 B.W.G. annealed) fathoms	8	200	600
Yarn, spun	28lbs.	56lbs.	1 cwt.

The method of forming bridge given in fig. 1, provides a roadway the slope of which does not exceed $\frac{1}{6}$th, and at the same time uses as much of the cables as possible to take the chesses directly upon them.

General description. The span is 100 ft. and the dip $\frac{1}{10}$th. The roadway is 5 ft. 8 in. wide between the ribands, so as just to take field guns. The cables are 7 ft. apart at the piers, and the anchorages consist each of a 15 in. round log 18 ft. long, at a mean depth of 3 ft. 6 in.

Calculations. Assuming the weight of roadway and cables to be 45 lbs. a foot run, and the dead load for infantry, two deep, crowded, to be $280 \times \frac{3}{2} = 420$ lbs., the total load is 465 lbs. a foot run, which (Table, page 63) gives a maximum stress of $465 \times 100 \times 1{\cdot}346 = 62{,}589$ lbs.: say 63,000 lbs.*

The cables, therefore, and each anchorage must be calculated to bear safely a tension of 63,000 lbs., acting (in the case of the anchorages) at a slope of $\frac{1}{2{\cdot}5}$; which (Table, page 63) is the slope of the back parts of the cable for the given dip.

Anchorages. The resistance per square foot in this case, at a mean depth of 3 ft., will (Table III., Paper VIII.) be found to be 6,010 lbs., and at 4 ft. 10,930 lbs.; 8,470 lbs. may, therefore, be taken as the resistance per square foot at 3 ft. 6 in.; hence, the total holding power will be $15 \times 1\frac{1}{4} \times 8{,}475 = 158{,}925$ lbs. in loam, which gives margin enough.

Cables. Two 10 in. hemp cables, each with a breaking weight of 36 tons, will allow a margin of safety of over $2\frac{1}{2}$, though a margin of safety of 3 would be better.

The stress due to a 9 pr. M. L. R. gun will be found to be much less than that for infantry. Taking its total weight with carriage to be 1·74 tons live load, (which multiplied by $\frac{3}{2} = 2{\cdot}6$ tons dead load) and that of the roadway, &c., at 2 tons, the maximum stress will (formula appendix A) not exceed the value given by the expression

$$\frac{1}{2}\sqrt{L^2 + \left\{\frac{l}{4d}(L + W)\right\}^2} = \frac{1}{2}\sqrt{4{\cdot}6^2 + \left\{\frac{10}{4}(4{\cdot}6 + 2)\right\}^2} = 8{\cdot}6 \text{ tons,}$$

or 19,264 lbs.

This is less than $\frac{1}{3}$rd the strain due to infantry; as far, therefore, as the cables are concerned, heavier guns could be passed over.

The two spars on each side which carry the chesses near the piers, if 6 in. in diameter, will be strong enough to carry 9 pr. M. L. R. guns; if lighter than 6 in., they can be slung at shorter intervals.

Chesses. Chesses 2 in. thick, (or $1\frac{5}{8}$th in,) would be strong enough to carry 9 pdr. M. L. R. gun wheels, the supports being nearly under the wheels.

Piers. The piers are evidently strong enough to resist the crushing load (1000 lbs. per square inch being safe). They should be tied back to the anchors as in fig. 8, to resist any oblique thrust on the bearings.

* This is not strictly correct, as about 5 ft. of the load on the road is carried by each bank.

Construction of bridge.

The line of bridge is marked out on both banks, the positions of the piers fixed, and a half section of the site and bridge traced on each bank. The excavations for the anchors are then picketed out, and each commenced by three diggers. As the slope of the cables behind the piers is $\frac{1}{2\cdot5}$, the height of the piers 3 ft., and the mean depth of the anchorages 3 ft. 6 in.; the front cutting lines should here be $2\cdot5\ (3 + 3\cdot5) = 16\frac{1}{4}$ ft. from the edges of the banks. A line is next got over, and the cables are dragged or floated across.

The pairs of road-bearers, E B (fig. 1), are now got ready by connecting them with 3 in. poles at A and B; the ends of the road-bearers at B, being only 6 ft., while at E they are 6 ft. 6 in. apart from out to out.

When the piers have been set up and the anchor-logs placed and covered, except at the grooves, the cable ends are passed under the anchor-logs and round them with a complete turn. This part of the work is done most quickly by hand, without tackles. The ends at one bank may be secured by bringing them alongside the standing part for about 8 ft., and seizing them in five or six places with strong tarred yarn (yarns of 2-in. rope are best for temporary use), which should be covered with pitch. Iron clamps (fig. 23) are more quickly used than yarn, but their holding power has not been tested with a heavy stress.

On the other bank, a treble and double tackle with 3-in. (white) rope is used to take in each cable after the men have hauled it in as much as possible by hand. The treble block is hooked to a selvagee made fast to the standing part, close to the pier head; and the double one to the running end, close to the anchor. A man with a crowbar eases the turns round the anchor, while a squad hauls on each fall; by this means, as the cable is brought in, the slack is at the same time taken up.

The cables, if of hemp, should be taken in as much as the power permits, as even a stress of $\frac{1}{8}$th the B.W. will stretch the rope about 4 ft. (Table V., Paper VIII.), and will give an increase of dip of several feet (Table, page 63). The ends are now securely seized to the standing parts, a small spar is placed across the cables at H (fig. 1), and the ends of the road-bearers are tied loosely to it, so as to hang down below it. This allows of their being pushed out to their proper positions. The road-bearers are then secured to the cables at A, B, with 1-in. rope, and the chesses are laid out as far as B on the road-bearers, and beyond it on the cables, to the points corresponding to B on the other side. As they advance, light 3-in. poles, C, D, are lashed across the cables to keep them at the proper intervals; and, if light sticks be available, they may be lashed diagonally under the roadway, as shewn dotted (fig. 4). At the points B on each side, where the first chesses are laid direct on the cables, there will be a step, unless the longitudinal road-bearers E, B, hang a little below the cables at B. The step, if any, can be filled up with a small fascine or planks. If hemp cables be used, the bridge, *when secured*, is loaded with men to stretch the cables.

When the men get off, some of the chesses, if necessary, may be removed at the fixed end, and the cables are hauled in as before at the other end, till they are, say, 2 feet above the required dip. After this the ends are secured, and the other pair of road-bearers got out, and the whole bridge chessed. If no further adjustment be required, the cable ends are finally secured, and the grooves filled in and rammed. The bridge is now racked down, long poles being best. The cross poles, B, C, D, if allowed to project, can be made to support posts for hand lines, on which canvas or great coats may be hung, if horses are to cross. Four guys are now secured to D, crossed under the roadway and anchored to the banks, and, if convenient, ties (B fig. 1), may be taken down and anchored below the bridge. With wire cables, the ends should be taken in until the dip is about $\frac{1}{15}$th or less; the roadway is then completed and weighted. The anchorages in taking their bearings will yield a little, but if the dip be still much less than $\frac{1}{11}$th, the cables can be slacked off till the required dip is given to them, which can be ascertained by the method already described. This will allow some margin for further stretching under heavier loads. The cable ends are now finally secured, as described in the case of those secured at starting.

Materials, &c., for suspension bridge of 100 feet span.

The following is an estimate of materials required for this suspension bridge, in addition to those at page 49.

Two 10 in. hemp, or 6 in. iron wire cables, each 28 fathoms.	
Two spars 15 feet (15 inches throughout) for anchors.	
Four ,, 25 ,, (6 ,, at tip) for road-bearers.	
Four ,, 12 ,, (4 ,, throughout) for transoms.	
Four ,, 12 ,, (3 ,, ditto) for transoms.	
Ten ,, 20 ,, (4 ,, ditto) for ribands.	
Two ,, 9 ,, (over 4 inches) for shore transoms.	
Forty rack sticks and lashings (8 feet)	
Two balks 15 ft. × 8 in. × 8 in. sills.	Piers.
Four ,, 3 ft. × 8 in. × 8 in. struts (inside).	
Four ,, 2 ft. × 8 in. × 8 in. caps.	
Four ,, 5 ft. × 8 in. × 8 in. uprights.	
Four ,, 6 ft. × 8 in. × 8 in. struts (outside).	
Four ,, 7 ft. × 8 in. × 4 in. back struts.	
Two 10 ft. to 15 ft. 8 in. × 4 in. anchors.	

Modifications of bridge.

In case guns have to pass such a bridge, and the planks are not thick enough when only resting on the cables which support them at 6 ft. intervals, the transoms A, B, C, D, &c., may be heavy (5 in. instead of 3 or 4 in.) and lashed loosely to the cables, so as to hang 3 in. below them. One or two balks can then be laid from transom to transom along the roadway, so as with the cables or side balks to give the necessary support to the planks. When the piers require to be so high that a transom can be used, they are better of the form shown in figs. 16 and 28. For infantry only, sloping banks may be stepped (fig. 2), when the necessity for piers is avoided, while the slope of the road is not excessive. In the above a very heavy load has been allowed for; much lighter cables could, of course, be used with light chesses to take infantry or guns, with precautions.

Suspension bridge with trestles.

The bridge, figs. 8 and 9, has a span of 130 ft., a dip of $\frac{1}{12}$th ; the roadway rises 1 in 30, and is 5 ft. 8 in. wide in the clear, the cables being 10 ft. apart, and the anchors consisting of two logs, each 18 ft. by 18 in. in diameter. The road is supported on trestles which form equilateral triangles, each side being 10 ft. and the height 8 ft. 6 in. As it appears desirable not to employ trestles much higher than this, low piers are used, by which 3 ft. is saved in the height of the trestles; while with spans of less than 100 ft., piers may be dispensed with, as in fig. 2.

Calculations, &c.

The weight carried by the cables is that of ten trestles and of about 90 ft. of roadway; each trestle weighs about 350 lbs., and the roadway may be taken at 65 lbs. per foot run of bridge. Hence, the weight per foot run is about 100 lbs., which with infantry, two deep, crowded $= 280 \times \frac{3}{2}$ is $= 520$ lbs. per foot run. As may be seen from fig. 8, only about 90 ft. of the cable is loaded, and considering this as a separate span, with a dip of 5 ft. or $\frac{1}{18}$th, as measured on the traced curve, the stress at the highest point will (Appendix A) be approximately =

$$520 \times \frac{90}{2}\sqrt{1 + \left(\frac{18}{4}\right)^2} = 107{,}874 \text{ lbs.*}$$

Four $8\frac{1}{2}$ in. hemp cables, each with a breaking weight of 28 tons, or two $4\frac{1}{2}$ in. steel wire cables, each with a breaking weight of 54·5 tons, are the smallest that will answer the purpose. Each anchorage will also have to stand safely a pull of 108,000 lbs. The resistance per square foot of surface, at a mean depth of 4 ft., to a force at a slope of $\frac{1}{3}$rd (the slope of the cables in this case) will be found from Table III., Paper VIII., to be 11,200 lbs. Hence, the resistance in this case, $= 11{,}200 \times 18 \times \frac{3}{2} = 302{,}400$ lbs.

The anchor itself would be most likely to fail by the cross-breaking of the 4 ft. 6 in. ends. Assuming the log to be of wood, with $f_0 = 8300$, the safe uniform load is got from the equation

$$\frac{W \times 4{\cdot}5 \times 12}{2} = \frac{8300}{3} \times \frac{22}{7} \times \frac{9^3}{4} = 58{,}686 \text{ lbs., and the maximum load is}$$

$4{\cdot}5 \times 11{,}200 = 50{,}400$ lbs., which allows a little margin.

The central 9 ft. will bear a greater load, and the resistance to shearing is also greater.

Construction of bridge.

The anchorages are marked out and excavated; the piers which are connected, as in fig. 13, are set up and stayed; the caps having iron bearing plates (fig. 10) if wire cables are to be used. The cables are got over and secured at one side, and the slack taken in at the other ends till the dip is about $\frac{1}{14}$th. The ends are now secured temporarily till the trestles are placed, when any slight difference in dip between the two cables may be rectified, and the trestle heads aligned from bank to centre.

* This approximation gives too high a value for the stress. What happens is, that the unloaded parts of the cable straighten, and allow the loaded parts to take a greater dip, thus diminishing the stress on the latter. To be accurate, the cable should be considered as a funicular polygon.

The ordinates, at 10 feet intervals from the centre, are calculated from the formula (Appendix A) $y = \frac{4\,d\,x^2}{a^2}$, and the half curves and the form of the banks traced on each side with a tape and pickets. Another tape shows the line of the roadway with a rise of $\frac{1}{20}$th, the position of each trestle being marked by a picket. The line of the intersections of the feet (G, D, E, &c., fig. 8) is also traced parallel to the roadway, and the intersections marked.

The two frames (fig. 11) for each trestle are then made; the position of the transoms and ledgers, which should be marked on the tape, and the points of intersection of the legs being obtained from the section, and marked. The feet of the diagonals should not project outside of the legs, and the feet of the latter should be cut off, so as to have them all the same length below the intersections. The small frames of each pair should have a clear width of 6 ft. 6 in. at the transom. When the frames are ready, each pair are locked, and those for each half-span are brought up in rear of the piers in their proper order, the small frames leading on one bank and following on the other; the half-frame L (fig. 8) of the central trestle being against K, and B against C. The feet of each trestle are now lashed together from D to E with a 2-in. lashing, so as to be 10 ft. apart at the points of intersection, and two temporary lashings are taken round each pair of transoms. The feet of all the trestles are then placed together, as when in position, and a couple of 3-in. ropes are passed alongside the trestle legs and over the cable ledgers (*d* fig. 11). They are lashed to the ledgers of trestle K, and a short 1-in. lashing is tied to them as a mark, just where they cross each of the other ledgers. The other ends of the cables are passed over the chasm, and each is manned by ten or a dozen men. The trestle K, with half of L lashed to it at E, is now carried forward and put out on the cables which are outside the feet. When K has been hauled out far enough, the next trestle is brought up; the feet of the two trestles are lashed at D, and the 3-in. ropes secured (where marked) to the ledgers. The two trestles are then hauled out, and a third added, and so on. Lastly, the frame A is put out and made to lock with B. The trestles on the other side are got out in the same way, and the two halves of L are made to lock.

The trestles are now adjusted, and the lashings between the feet racked up if necessary. The cable ledgers should then be lashed with 1 in. lashings to the cables, those near the piers being strengthened by rope ties, as in fig. 11. The drag ropes are now cast off, and the trestles are ready for the balks, which are passed out and placed, the ends of the outer ones being spliced (fig. 3), and lashed to each transom, while the inner ones overlap. The chesses are then laid, those coming between the trestles being cut to 6 ft. 4 in. The ribands, in double lengths of 20 ft. if available, are then laid continuously over the outer balks, breaking joint over the middle of the spans, and are racked down with wire, if possible, just outside each transom and in the middle of each span, two lashings being used at the butts. These wire lashings have an end fastened to the riband, and each turn is tightened up by taking a half hitch with the wire round a stick 2 or 3 ft. long, which is used as a lever. Wedges are also driven on the outside of the ribands between them and the wires. After the roadway is finished, if the dip be less than $\frac{1}{13}$th, the cable may be eased off to that amount, (though this is seldom necessary,) the ends finally secured, and the anchorages filled up. A light hand rail of rope may then be added, and the bridge is guyed with a pair of guys from the middle of the cables to each bank, and also, if possible, from the head of the central trestle just below the transoms to the same points or to knots on the first guys. It has been found that the whole of the trestles can be passed out from one side, but time is saved by working from both sides, when possible.

Division of Labour.

The following division of labour will be found convenient, the reliefs being of eight hours.

1st relief—1 non-commissioned officer and 20 men, making and bringing up trestles; 8 men making anchorages; 6 carpenters making piers; 4 carpenters preparing road-bearers and ribands; 1 non-commissioned officer and 20 men getting over cables.

2nd relief—Forty men, 20 on each side, securing and tightening cables, and afterwards getting out trestles.

3rd and 4th reliefs—Twenty men adjusting trestles.

5th relief—Thirty men forming roadway, racking down, and fixing guys, handrail, &c., and making up bridge ends.

Materials, &c., for Suspension Bridge of 130 feet span.

The following is an estimate of materials required for this suspension bridge, in addition to those on page 49:—*

Four $8\frac{1}{2}$ in. hemp, or two $4\frac{1}{2}$ in. steel wire cables, each 36 fathoms.
Two logs 18 ft. (18 in. diameter throughout) for anchors.

Forty-four	spars	13	feet	(3 in. at tip) for trestle legs.	
Forty-four	„	15	„	(2 in. at tip) for diagonals.	
Twenty-two	„	9	„	(4 in. throughout) transoms.	
Eight	„	12	„	(2 in. throughout) ledgers.	
Twenty	„	12	„	(5 in. throughout) cable ledgers.	
Two	„	10	„	(5 in throughout) shore transoms.	
Forty	„	14	„	(5 in. throughout) road-bearers.	
Eight	„	16	„	(6 in. throughout) ditto.	
Twenty-eight	„	20	„	(5 in. round flatted) for ribands.	
Two	balks	18 ft. × 10 in. × 10 in. sills.			
Four	„	3 ft. × 10 in. × 10 in. uprights.			
Four	„	2 ft. × 10 in. × 10 in. caps.			Piers.
Four	„	4 ft. × 10 in. × 10 in. struts (outside).			
Four	„	2 ft. 6 in. × 10 in. × 10 in. ditto (inside).			
Four	„	7 ft. × 8 in. × 4 in. back struts.			
Two	„	10 ft. to 15 ft. × 8 in. × 4 in. anchors.			

Ordinary suspension bridge. General description.

The bridge (figs. 16 and 22), has a span of 200 ft., and a width of roadway of 5 ft. 8 in. in the clear, so that the ribands may act as wheel-guides. In this case, the whole roadway hangs from the

* Bamboos would make good trestles, and would be very light.

cables, which should be at least 1 ft. above the road at the centre, allowing a rise of $\frac{1}{30}$th. The cables are supported on timber piers (fig. 28) with a broad cap of hard wood, trenailed and dogged to the top of the standards, and grooved to receive two flat plates as in fig. 10 (or of a curved section to fit the cables), on which the cables rest, 9 ft. 6 in. apart.

Roadway. The roadway consists of transoms, carrying road-bearers which support chesses (fig. 18) racked down with double ribands. As the bridge is for heavy traffic, a pair of struts, footed on the banks, are used to diminish the distortion; the first transom is carried entirely by the ties E and the struts B. The second is chiefly, and the third partly, supported by these struts.

Calculations, &c. Though the cables are slightly relieved by the above arrangements, it is simplest to consider them as uniformly loaded to get the maximum stress. The uniform load on the cables is about 90 lbs. a foot run, and infantry, two deep, crowded, $= 280 \times \frac{3}{2} = 420$ lbs. Hence, the dead load per foot run $= 510$ lbs., and (Table, page 63) the maximum stress $= 510 \times 1{\cdot}346 \times 200 = 137{,}292$ lbs; while, if we take the dead weight of the 64-pr. M.L.R. gun at 5 tons $\times \frac{3}{2} = 7{\cdot}5$ tons, and that of the roadway at 8 tons; the maximum stress in tons due to this gun will not exceed the value of the expression

$$\frac{1}{2}\sqrt{L^2 + \left\{\frac{a}{4d}(L + W)\right\}^2} = \frac{1}{2}\sqrt{15{\cdot}5^2 + \left\{\frac{10}{4}(15{\cdot}5 + 8)\right\}^2}$$

$$= 30{\cdot}3 \text{ tons, nearly.}$$

The same load, if all uniformly distributed, would (Table, page 63) have caused a stress of $15{\cdot}5 \times 1{\cdot}346$ tons $= 20{\cdot}86$ tons, or about two-thirds the above.

Two $5\frac{1}{2}$ in. steel wire hawser-laid cables, each with a breaking weight of say 75 tons, would allow a factor of safety for infantry of about $2\frac{1}{2}$, and would be strong enough, as the allowance for live load has been made; while for the gun alone, two 4 in. or even $3\frac{1}{2}$ in. cables could be used.

Length of Cables. Allowing 40 ft. below ground for each anchorage, each cable must be $40 \times 2 + 2{\cdot}7 \times 24 \times 2 + 200 \times 1{\cdot}027 = 415$ feet, or say 70 fathoms.

Anchorages. The anchorage, figs. 5 and 15, is arranged for sand. It will be seen that for each foot run there are 4 square feet at mean depths respectively of 2, 3, 4, and 5 feet. Then, taking a mean between $\frac{1}{2}$ and $\frac{1}{3}$rd for the slope of $\frac{1}{2{\cdot}5}$ (E B, fig. 5,) the holding power of the anchorage per foot run is (Tables II. and III., Paper VIII.) 50,961 lbs. in loam, and 25,480 lbs. in sand. A length of 16 feet of this anchorage will therefore give a holding power of 407,680 lbs, or three times the maximum pull on the anchorage. For cross-breaking resistance, the log round which the cable is taken should have a diameter of 20 in., and this will also be ample for shearing resistance. *

* In the following description of bridge, round timber and rope fastenings have been chiefly used; with square timber and iron fastenings, better and stronger piers could be made, and a lighter and stiffer roadway might be formed of planks, balks, and ribands. A bridge of nearly the above span has been made at Chatham, and has carried 64-pr. guns, the slings being of hemp, and the roadway that of the new pontoon superstructure.

A method of securing cable ends above ground, so as to allow of the slack being taken in when required, is shewn in figs. 6 and 7.

Strength of pier standards. The diameter of the standards (fig. 28) (each of which has to carry 70,000 lbs. safely, or 280,000 lbs., using a factor of safety of 4,) is obtained from the equation $280{,}000 = \frac{\pi d^4}{4\,(12 \times 26)^2} \times 3{,}000{,}000$, whence $d =$ 9 in.; but to give a good bearing for the caps, logs from 10 in. to 12 in. in diameter are used.

Strength of slings. For the slings, the greatest load on each is that due to the gun $= \frac{1}{2}\,(11{,}200 + 90 \times 10)$ lbs. $= 6050$ lbs.

The road-bearers and transoms have been calculated, and suitable sizes are given for them; the transoms, from the positions of the baulks, are subject to only about $\frac{4}{7}$th the stress due to a uniform load.

Construction of bridge. The line of bridge is fixed, and the anchorages marked out and commenced by four men at each side, while two men prepare the footings for the piers on each side. These piers consist of a frame with side and back struts (figs. 16 and 22) and back stays. These stays allow of the piers being placed close to the edges, thus shortening the span. When the piers are put further back from the edges, the back stays may be replaced by front struts. The piers are framed together (standards 9 ft. apart in the clear), the back struts are laid out in rear of the frames, and lashed loosely at their tips to the standards below the caps. The back stays are also secured round the caps, just inside the cable-bearings, which should be exactly over the centre of each standard. Anchorages are provided for these stays by two diggers at each end, who bury a log (12 ft. by 12 in.) at each bank, to a depth of $3\frac{1}{2}$ ft.; the ties are taken round these, but not finally secured. A couple of guys are also secured to the heads of the standards, and the bearings are greased. While this is being done, the cables are passed across and laid on either side of the positions of the frames, and secured, if necessary, to pickets. The frames are now raised by hand, props being employed at each lift till the back struts can be used to shove up. This avoids using fore-guys, which, with such a span, are inconvenient, though, wherever they can be used, they are much safer than props and poles, and should be employed.

When the frames are up and hanging forward on the back-stays, the back struts are put into the footings, the frames being pulled back a little towards the bank. The slack of the back-ties is now taken in, and they are secured; and while each cable is being raised, a head guy is used on the further side of the frame to steady it. To raise the cables at the first pier, a double and treble, or single and double, tackle, with a 3-in. fall, is secured to the tip of each of the poles which are to act as side struts; these poles are then raised up alongside each standard (fig. 28), and two men go up by the back-stays and lash the poles to the caps just inside the cable plates. A long bridle of spun yarn is used (fig. 17), secured to each cable to the right and left of where it should bear on the cap, and each bridle is hooked to the lower block of the fall on its own side; a snatchblock is now lashed to each standard, 3 ft. above the ground, and the running end of each fall led through it to the rear. The cable ends being sufficiently secured, the cables are now raised, dropped into their places, and cleared of the bridles. The blocks are then transferred to the cap, where they are secured near the cables, and the spars are partly unlashed and their feet drawn out, till they are in the proper positions as struts. Their feet should be let into the ground, and should rest on a block or plank. They are then finally lashed to the standards and cap, when the side guys may be removed.

By this time the anchorages should be ready. The cable ends (fig. 5) are passed round the beam B, (the sheeting pieces, except the bottom one, being added after the turns have been taken), and the earth filled in and rammed. The squads may now go over to help on the other side, and return when the cables are taut. The other ends of the cable are now passed round their anchor beam B, and seized, but without taking in the slack, and the anchorages are sheeted and filled up, with the exception of the grooves. The arrangements for raising the cables on the second pier are the same as before, except that treble and double tackles are used; when the cables are placed and the pier completely strutted, a treble block is hooked to a strong selvagee which grips the standing part of the cable near the anchorage; the double block is similarly secured to the running end which has been taken with a complete turn round the anchor beam B (fig. 5). A squad then mans each tackle (3-in.) and takes in the slack*, a man at each anchorage easing round the turns; if these jam, the standing part can be hauled in by fastening the double block to the anchor beam. The cable should be hauled up till the dip is $\frac{1}{12}$th or less; this can be ascertained by marking the corresponding height on the uprights of the piers and sighting the bottoms of the curves.

The cable ends are now seized to their standing parts for as great a length as is convenient. The ends of the ties, (E fig. 16) are taken up by the two blocks fixed to the pier caps, and the ties are secured round the cap outside the cables, their lower ends being brought ashore. A 14-ft. spar (about 3 in. or 4 in. in diameter), with two 20-ft. rope ladders attached to it (each about 4 ft. from the centre of the spar), is now raised by the pier blocks, its ends passed over the cables, and preventer-ropes, secured to each end, are taken over the pier heads and down below so as to be let out as required. A man with two 1-in. lashings then goes up each ladder, and by supporting his weight on the cable, eases down the spar or *traveller* until it is below the point C. Instead of these travellers, a chess may be slung by ropes from shackles (fig. 24) working on each cable.

The spars B C, are now laid, tips to the bank, just outside the piers; the falls from the blocks are secured at about 10 ft. from the tips, and the spars are pushed and hauled out till the points, D, pass the piers, when the transom, D, is lashed on, and the ends of the ties, E, taken round it.

* It has been found, experimentally, that with wire ropes the effective power required to haul them in over the pier-caps is about 33 per cent. greater than the theoretical strain at the highest point. Thus, in this case to draw up a cable of 26·5 lbs. weight per fathom to a dip of 1-12th, the strain (Table, page 63) $= 1{\cdot}58 \times \frac{200}{6} \times 26{\cdot}5 = 1{,}400$ lbs., and the power required would be $1{,}400 + \frac{33 \times 1{,}400}{100} = 1{,}862$ lbs.; with five turns in the blocks, the loss of power is $10 \times 5 = 50$ per cent.: hence, the work to be done may be considered $= 1{,}862 \times 1{\cdot}5$, and with a power of 4 to 1, the number of men required would be at least $\frac{1{,}862 \times 1{\cdot}5}{4 \times 80} = 9{\cdot}16$, or 10 men, allowing each man to pull 80 lbs.; as, however, the operation takes some time, it is better to employ 15 or 20 men, so as not to overstrain them.

The butts of the spars are then pushed down into footings prepared for them, and the men on the ladders at once lash the tips to the cables at C, and at the same points secure the slings for the second transom, they also transfer the ends of the falls from the pier blocks to their spar, and cast off their preventer ropes.

The ties, E, are now made taut, and the roadway made out to D; the second transom is then secured to its slings at the proper height, and the roadway extended to it. Much time is saved if slings in a single piece and of about the proper length can be used. Each of the slings should have an eye-splice with a thimble at one end, and should be provided with a shackle (fig. 24) large enough to pass over the cable; on the steep parts the shackles are kept from slipping by a selvagee secured below them, and then passed above and fastened as with a stopper. Another form of fastening is the screw clamp, shewn at fig. 23, where a couple of plates about $2\frac{1}{2}$ in. by $\frac{3}{16}$ in. are clamped to the cable. Even when there are no shackles or clamps, it is better not to tie the slings to the cables but to stopper them as above, as their position can then be more quickly shifted when required. In this way, by means of the travellers working from both ends, all the slings are fixed along the cables at 10 ft. intervals, the transoms supported, and two road-bearers placed at each bay, so as to carry four or five chesses. The slings must now be adjusted. To commence at the third transom, the traveller or a similar spar is brought directly above it, and two railway coupling screws are slung from the traveller, each about a foot inside the cables. These couplings are completely unscrewed or partly screwed up, according as the transom wants raising or lowering. The couplings are fastened to the latter and screwed up to take the load off the slings, and the required adjustment is made, allowing for the probable slacking of the slings, which are then secured to the transoms (in the case of a single sling, by a round turn and seizing) (fig. 24). When the cables are too close to the road to use the screws, the traveller can be used as a fulcrum for two long levers which prize up the transom as required.

The adjustment must be done equally on both sides, and the bridge must be cleared now and then to judge of its correctness.

In the case of the third transom on each side, two oblique slings are used to replace the temporary vertical one.

The roadway is now formed by adding the outer baulks, which are spliced as in fig. 3, only with a shorter splice; the undersides of the ends may be flattened, and the splice is securely lashed with 1-in. lashings to the transom, which may also have cleats for the baulks, and 1-in. trenails to keep the slings on (fig. 18). The inner baulks which overlap are placed not more than 12 in. inside each outer one, the chesses are laid down, and, as the outer baulks are continuous, the ribands can be laid continuously over them; these may consist of 5-in. or 6-in. spars, the lower one flatted on both sides, and the upper on one side. They should be in long lengths—20 to 30 ft.—and break joint, as shewn. After the final adjustment of level, both are racked together (with wire if possible) to the outer baulks, as shewn in fig. 16. These deep ribands act as good guides, but above all, they stiffen the roadway, and also take much of the weight off the outer baulks. If only thin chesses be available, all roadways are much helped by using planks longitudinally (as in figs. 18 and 19) nailed to the chesses in the wheel tracks; these spread the load and save wear on the cross chesses.

Another point to be remembered is that the rope rack lashings must be protected by cleats nailed to the ribands, which prevent the wheels from cutting them.

Wind and stiffening guys and handrails are added, the travellers, blocks, and tackles taken down, and the bridge is ready for use after the fastenings of the cables and slings have been carefully inspected.

To give means of finding the length of the slings, the values of y (fig. 12), are given below for this curve. When convenient, the half curve may be traced out on the ground.

Values for x, in feet.	Corresponding values for y, in feet.	Values for x, in feet.	Corresponding values for y, in feet.	Values for x, in feet.	Corresponding values for y, in feet.
0	0	35	2·45	70	9·8
5	0·025	40	3·2	75	11·25
10	0·2	45	4·05	80	12·8
15	0·45	50	5·0	85	14·45
20	0·8	55	6·05	90	16·2
25	1·25	60	7·2	95	18·05
30	1·8	65	8·45	100	20·0

The following distribution might be made of the working parties in each relief of eight hours; smaller numbers could do the work, but more slowly.

Distribution of labour.

1st Relief.—16 diggers for anchorages and footings, 1 N.C.O. and 20 men passing over cables and helping to raise frames*; 2 N.C.O. and 20 men, (10 on each side,) forming frames and raising and securing them; 4 carpenters preparing anchorage timbers and road-bearers.

2nd Relief.—12 men, 6 on each side, forming anchorages and getting cable ends placed; 2 N.C.O. and 40 men (in four squads of 10) raising derricks and cables, hauling taut, and placing road transoms; 8 carpenters notching chesses and preparing transoms, baulks, and ribands.

3rd Relief.—20 men, 10 on each side, placing transoms; 10 men preparing and bringing up road superstructure.

4th and 5th Reliefs.—20 men adjusting transoms and main cables.†

6th Relief.—30 men laying roadway, racking down, and completing bridge.

Materials, &c., for suspension bridge, of 200 feet span.

The following is a list of materials and tools for this suspension bridge, in addition to those given in Page 49.

* In some cases 40 to 50 men may be required if the cables have to be moved far.

† With convenient materials, the adjustment of road-bearers might, perhaps, be done in one relief; it is by far the most tedious part of the work, and may take longer than above stated.

Two $5\frac{1}{2}$-in. steel wire hawser laid cables, each 68 fathoms.
Four spars 26 feet (10 in. at tip), for standards.
Four spars 22 feet ($3\frac{1}{2}$ in. at tip), for diagonals.
Two baulks 12 ft. × 10 in. × 9 in. of hard wood, for caps.
Two „ 15 ft. × 10 in. × 10 in. for ground sills.
Four spars 36 ft. (4 in. at tip) for back struts
Four „ 32 ft. (3 in. at tip) for side struts.
Four „ 30 ft. (5 in. at tip) for cable props.
Two „ 30 ft. (3 in. at tip) for horizontal frame ties.
Forty spruce spars 20 ft. (6 in. throughout) for ribands.
Eighty „ 13 ft. (6 in. throughout) for road-bearers.
Nineteen „ 10 ft. (6 in. throughout) for transoms.
Two spars 10 ft. (over 4 in.) for shore transoms.
Two „ 14 ft. (4 in. throughout) for travellers.
Four hundred feet run of plank, 12 in. by 1 in., for wheel planks.

Sixteen spars 5 ft. (7 in. at tip)	for anchorages.
Two „ 16 ft. (20 in. throughout)	
Two „ 16 ft. (12 in. $\frac{3}{4}$ round)	
Ten „ 16 ft. (8 in. $\frac{1}{2}$ round)	

Four back ties, 9 fathoms each, of 2-in. steel wire rope.
Four ties (E), 6 fathoms each, of $1\frac{1}{2}$-in. steel wire rope.
Forty slings, total 96 fathoms of $1\frac{1}{2}$ in. steel wire rope.*
Four guys (3-in. hemp) 8 fathoms each, for raising piers.
Four screw couplings.
Eight cable seizings of iron (or copper) wire 20 B.W.G., 4 fathoms each.
One hundred $2\frac{1}{2}$-in. nails for wheel planks.
Four rope ladders, 20 ft. each.

Other applications of the suspension principle.

When a central point is available, a bridge may be formed with one pier only (fig. 21), the cables being anchored on each bank, as in fig. 14, and struts used at the piers and banks, in the latter case to keep the roadway from dropping below the banks. The strains on the piers and anchorages correspond to the strains at the highest and lowest points in a complete span of double the half span; less anchor power and less length of cable are in this case necessary; one pier also is saved. When piers are placed on points isolated from the banks, two complete half spans may be formed behind each pier; these half spans may be considered similarly to the above. When only a few slings are used behind the piers, their resolved effect along the cables helps a little to diminish the pull on the anchorages. In India, thick ropes of creepers are suspended, two above and one below (fig. 20), and fastened at intervals to forked branches. A man can cross by walking on the bottom cable and holding the upper ones. In the absence of better means, a single cable can be applied to carry loads across a chasm, as shewn in figs. 26

* This rope, or 1-in., would be also better for guys than pontoon cables, if it be available.

and 27. When the load is heavy compared to the cable, the latter will form two nearly straight lines, and the strain at the centre can be got directly, but with a heavy cable the formula Appendix A for a concentrated load must be used. A block or a travelling pulley is required from which to sling the load; this is dragged across by one rope, and checked by another. To work both ways, the piers should be of the same height; but if it be required to pass loads one way only, a small pier is best on the further side (fig. 27). The load should be fastened at A to the cable, which should then be hauled taut enough to lift it, and on reaching the other bank it should just land clear. Means of tightening up the cable are required.

The piers may be four legged trestles, the clear width at the transoms being only one or two feet—enough to give a good bearing to the cable—or a pair of sheers may be used on each bank, the cables resting on a short cross-piece lashed to both legs just below the fork; or each may have a gyn tackle, the lower block of which is secured to the load; by slackening off one and hauling on the other, the load can often be passed over more easily than with a cab'e. For men, &c., a cradle is convenient.

A use to which suspension cables have been applied on a sea-beach, for passing the surf, is shewn in fig. 25. When the depth permits, it is better to use long spars on the bottom instead of stepping them on a raft.

In India, a single telegraph wire often supplies a means of passing letters and dispatches across ravines liable to torrents, or enables a man to ford them by having a hand-line attached so as to travel along the wire.

Appendix A.

Formulæ for the calculation of the stresses.

Suspension bridges are calculated on the assumption that the load is uniformly distributed along a horizontal line, in which case the curve of the cable is a parabola. In fig. 12, let a be the total span, d the droop (both in feet) and w the load in lbs. per foot run of bridge; also let θ be the angle made with the horizontal by a tangent to the curve at its lowest point; ϕ the angle made with the horizontal by a tangent at B, then

$$\text{Horizontal tension at D the lowest point} = \frac{wa^2}{8d}.$$

$$\text{Tension at either pier, if of the same height} = \frac{wa}{2}\sqrt{1 + \left(\frac{a}{4d}\right)^2}.$$

When in addition to the uniform load there is a concentrated load W, the maximum tension is, with ordinary dips, that at the piers when W is at the centre. Then if $L = wa + W$ the maximum tension is approximately

$$= \frac{1}{2}\sqrt{L^2 + \left\{\frac{a}{4d}\,(L + W)\right\}^2} *$$

This formula is most easily worked in tons.

In all these cases when the tension in one cable is being considered, the total load must be divided by the number of cables.

* For this very convenient formula we are indebted to Lieutenant Darwin, R.E.

Length of the cable between the piers $= a + \dfrac{8d^2}{3a}$

$$\tan\theta = \frac{4\,d}{a}\ ;\ \tan\varphi = \frac{8\,d\,x}{a^2} \ \text{and}\ y = \frac{4\,d\,x^2}{a^2}$$

If e be the small elongation of the cable due to stretching or change of temperature, then the corresponding small depression $= \dfrac{3a}{16\,d} \times e$.

In fig. 12, A E may practically be taken as straight; therefore, to get the load to act vertically down A D, make E D = D C. Then the vertical load on the whole pier at A (or H) = 2 × weight on the cables from the highest to the lowest point $= w\,a$.

Table of Stresses in Suspension Bridges.

The following table will be found useful for calculating suspension bridges; in it the load is $w \times a$:

Dip.	Tension at lowest point.	Tension at highest point.	Length of Cable.	Depression at centre due to an elongation of Cable of 1 inch.	Value of D E (fig. 12).
$\frac{a}{10}$	1·25 × load.	1·346 × load.	1·027 × span.	1·875 inches.	2·5 A D
$\frac{a}{11}$	1·375 ,,	1·49 ,,	1·022 ,,	2·0625 ,,	2·75 A D
$\frac{a}{12}$	1·5 ,,	1·58 ,,	1·0185 ,,	2·25 ,,	3·0 A D
$\frac{a}{13}$	1·625 ,,	1·7 ,,	1·0158 ,,	2·4375 ,,	3·25 A D
$\frac{a}{14}$	1·75 ,,	1·82 ,,	1·0136 ,,	2·65 ,,	3·5 A D
$\frac{a}{15}$	1·85 ,,	1·94 ,,	1·012 ,,	2·815 ,,	3·75 A D

Appendix B.

Measurement of stresses.

In order to test the tensions in a suspension cable, the stresses due to its own weight, considered as a uniform load, and afterwards those due to that weight and to a concentrated load, were measured by means of a hydraulic dynamometer applied to a 6½-in. wire cable (weight per fathom 40·6 lbs.), which had been used for a suspension bridge of the form shewn in fig. 8, but with a span of 127 ft. The dynamometer was secured to the cable, just in front of a pier, and in the prolongation of the cable; that is, in line with the tangent at the highest point. By this means the stress in the cable at the highest point was read with tolerable accuracy. The results of the experiments are contained in Tables I and II. In Table I the calculated stresses were obtained from the Table in Appendix A; while in Table II, the formula given for a concentrated load was used, which, as will be seen, gives results in all cases on the safe side. In Table II, δ was the amount of vertical descent of the point of application of the concentrated load, after that load had been applied.

TABLE I.

No. of Experiment.	Dip of Cable.	Slope at highest point.	Measured stress. lbs.	Calculated stress. lbs.	REMARKS.
i.	$\frac{1}{9}$th	..	996	..	The stresses were also read with the dynamometer in prolongation of the back part (A E, fig. 12) of the cable, and the readings were as follows :— For $\frac{1}{10}$th = 736lbs. For $\frac{1}{11}$th = 765lbs. For $\frac{1}{12}$th = 968lbs. Showing a considerable amount of friction on the greased iron bearings on the head of the pier.
ii.	$\frac{1}{10}$th	21°	1068	1184	
iii.	$\frac{1}{11}$th	..	1170	1311	
iv.	$\frac{1}{12}$th	17° 10′	1370	1390	
v.	$\frac{1}{15}$th	14° 10′	1732	1707	
vi.	$\frac{1}{16\cdot7}$th	..	2038	..	
vii.	$\frac{1}{20}$th	..	2296	..	

TABLE II.

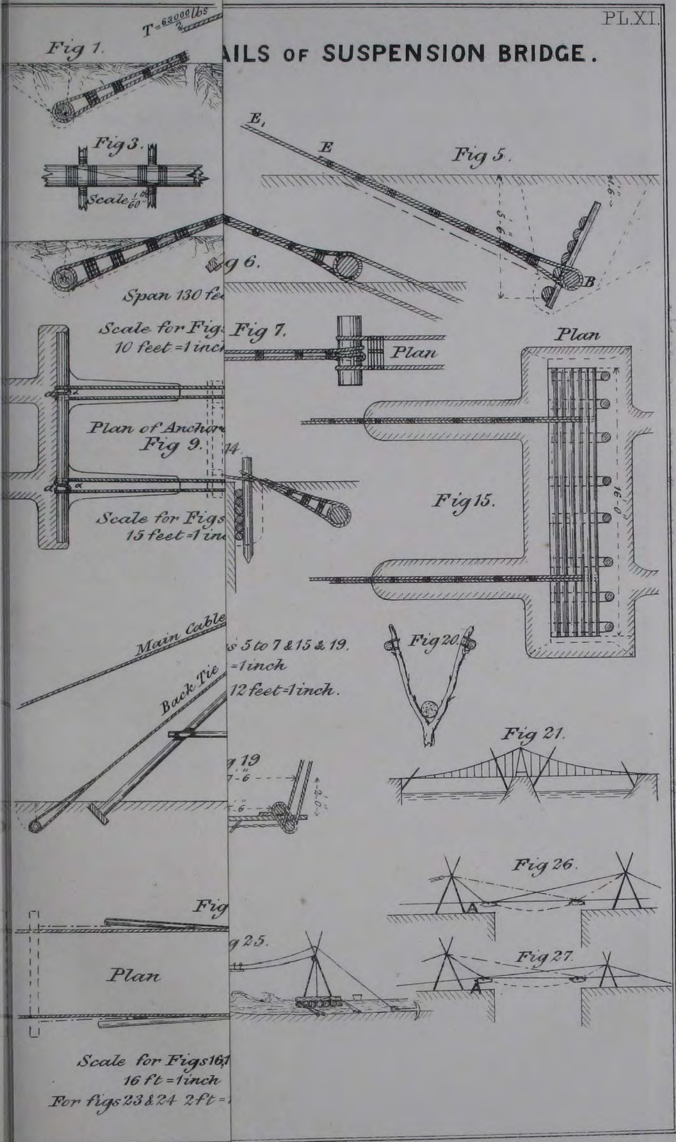
No. of Experiment.	Dip of Cable.	Value of δ in feet.	Slope at highest point.	Slope at centre.	Concentrated load. lbs.	Measured stress. lbs.	Calculated stress. lbs.	Per centage of error.	REMARKS.
viii.	$\frac{1}{10}$th	1·28	17° 10′	2° 20′	406	1848	2210	19·6	These stresses were with the concentrated load at the centre. With the same weight (406 lbs.) hung on the cable at 3 ft. from the pier, the stress, with a dip of $\frac{1}{10}$th, was only 1250 lbs., and with $\frac{1}{12}$th, 1680 lbs., (and the values of δ were 1·25 ft. and 0 66 ft.) This seems to show that the concentrated load produces the maximum effect at the centre in the case of dips, such as were here experimented on.
ix.	$\frac{1}{10}$th	1·72	17° 25′	3° 20′	910	2815	3455	18·25	
x.	$\frac{1}{12}$th	1·0	14°	3°	406	2397	2618	8·4	
xi.	$\frac{1}{12}$th	1·43	13°	4°	910	3725	4103	9·0	
xii.	$\frac{1}{16\cdot7}$th	1·7	..	...	610	3780	...	...	
xiii.	$\frac{1}{16\cdot7}$th	1·8	..	...	910	4424	...	...	
xiv.	$\frac{1}{16\cdot7}$th	2·25	..	...	1022	4648	...	...	

Effect of an oblique force.

In order to test the effect of an oblique pull at the centre of the cable, such as might be caused by a flying bridge working on it, stresses of 610 lbs. and 910 lbs. were applied at the centre of the cable when the dip was $\frac{1}{16\cdot7}$th, and instead of acting vertically, they were caused to act obliquely at a slope of $\frac{1}{4}$, (but in plan perpendicular to the plan of the cable); when it was found that they produced stresses at the piers of 3,060 lbs. and 3,808 lbs., respectively, which are roughly $\frac{4}{5}$ths of those in experiments XII. and XIII. In the absence, therefore, of a more exact method, such oblique pulls may be calculated to produce stresses, little, if any, less than if acting vertically.

PL.XI.

AILS OF SUSPENSION BRIDGE.



Distortion of bridge.

The following Table shows the amount of vertical distortion observed in a Suspension Bridge of 180 feet span and 18 feet dip, and similar to that in fig. 16, Pl. XI., except that the transoms were at 7 ft. 6 in. intervals. The load was a 64-pdr. B.L.R. gun, total weight 99 cwt.

TABLE III.

With hind wheels over No. 1 transom.		With hind wheels over No. 6 transom.		With hind wheels over No.12 transom.		With hind wheels over No.16 transom.		With hind wheels over No.22 transom.		With hind wheels over No.23 transom.		After gun had crossed.	
No. of transom where reading was taken.	Vertical displacement. feet	No. of transom where reading was taken.	Vertical displacement. feet	No. of transom where reading was taken.	Vertical displacement. feet	No. of transom where reading was taken.	Vertical displacement. feet	No. of transom where reading was taken.	Vertical displacement. feet	No. of transom where reading was taken.	Vertical displacement. feet	No. of transom where reading was taken.	Vertical displacement. feet
2	− 1·64	1	− 1·27	1	+ 0·02	1	+ 0·3	1	+ 0·04	1	+ 0·01	1	0
6	− 0·23	2	− 0·82	2	− 0·12	2	− 0·3	2	− 0·12	2	− 0·23	2	− 0·41
11	+ 0·15	11	+ 0·02	6	+ 0·38	6	+ 0·85	6	+ 0·28	6	+ 0·25	6	− 0·06
12	0	12	+ 0·3	11	− 1·4	11	− 0·1	11	− 0·42	11	+ 0·2	11	− 0·29
13	+ 0·54	13	+ 1·11	13	− 1·56	12	− 0·68	12	− 0·26	12	− 0·3	12	− 0·5
16	+ 0·15	16	+ 1·34	16	− 0·59	13	− 0·83	13	− 0·06	13	− 0·2	13	− 0·41
22	− 0·03	22	+ 0·47	22	+ 0·32	22	− 0·13	16	− 0·63	16	− 0·64	16	− 0·59
23	+ 0·1	23	+ 0·18	23	+ 0·23	23	− 0·12	23	− 0·62	23	− 0·33	23	+ 0·18

PAPER V.

RESULTS OF EXPERIMENTS IN BREACHING, BY MEANS OF HIGH ANGLE FIRE, MADE AT GRAUDENZ, 1873. *

BY LIEUTENANT T. FRASER, R.E.

Since 1864, the attention of the German Artillery has been turned to the development of indirect fire, and experiments had been made which led to the successful use of indirect fire, at Strasburg, and elsewhere, in the war of 1870-71. In order, however, to obtain further data, the experiments, described hereafter, were carried out during the siege operations, at Graudenz, last year.

The fortress of Graudenz dates from Frederick the Great; its revetments are of brick, with stone footings, and with a backing, in some places, of rubble masonry (Pl. XII, fig. 2). The escarps have demi-revetments, and, in the case of the bastions, appear to have counter-arches (Pl. XIV). The bricks are of large size, and the mortar fairly good; the whole being well consolidated by time. The earth of the parapets consists of a friable loam, which, however, stands at a steep angle when not broken up.

The following appear to be some of the points on which information was sought:—

1st. The best way of forming a breach, whether by horizontal and vertical cuts, or otherwise, and the number of rounds required for a given description of gun.

2nd. The relative efficiency of the different guns, and the effects of varying the velocity at striking.

3rd. How small a horizontal angle the line of fire may make with the revetment.

4th. The effect, in breaching, of using a slow percussion fuze instead of the ordinary one.

The natures of ordnance used were strengthened 12 C.M. (4¾ in.) gun, with a 32 lb. shell, including a burster of 1·1 lbs.; the long and short 15 C.M. (or 5·9 in.) guns, with 63 lb. shells, including 3½ lb. bursters; and the short 21 C.M. (or 8¼ in.) howitzer, with a shell of 176 lbs., including a burster of 11·2 lbs.

* The information contained in this paper was obtained with the help of Lieutenants J. C. L. Campbell and S. Hamilton, R.E. The German officers we met showed us every kindness, and provided us with full particulars, which we were authorised to make use of.

Nature of experiments.

The principal experiments were :—

I. Comparative experiments in penetration with 12 C.M. and short 15 C.M. guns (A fig. 1, Pl. XII.)

II. The breaching of a caponier (C fig. 1).

III Test of the penetration of the 15 C.M. (coil) gun (B fig. 1).

IV. The breaching of the right face of bastion IV. (D fig. 1).

V. The breaching of the right face of ravelin III. (E fig. 1).

VI. The breaching of the right face of ravelin IV. (F fig. 1).

In all the experiments, the effects were observed from a counterscarp gallery, and were communicated to the battery by means of a field telegraph. The ranges were all known, and the weather was calm and dry. The portion of each wall to be fired at, was marked off in squares with a side of 1 metre (figs. 5 and 11, Pl. XII.) Wherever final velocities are given, they are in feet per second, and the number of rounds given on each day, are the totals including those fired on the previous day (or days).

Experiment I. Penetrations.

Experiments were carried out against the left face of bastion IV, with strengthened 12 C.M. and short 15 C.M. guns, placed on the glacis with their muzzles about 3 feet above the cordon of the escarp.

The details are given in Tables I and II, where the comparative penetrations of the two guns are shewn. Figs. 6 to 8 give sections through the horizontal cut after different rounds; this cut was begun at the 16th shot.

The 12 C.M. gun was fired with a charge of 3·3 lbs., which gave a velocity of impact of 1,066 feet a second. The 15 C.M. gun with charges of 2·2 and 3·3 lbs., with velocities of impact of 657 and 821 feet a second respectively.

By comparing rounds 1 to 16, it will be seen that owing to their higher velocity the 12 C.M. shells had, if anything, a greater penetration than those of the 15 C.M. gun; while their penetration was considerably greater when the charge of the latter was only 2·2 lbs. The penetration of ten 12 C.M. shells at the same spot was 4·6 feet; while in 42 rounds the penetration was 8·25 feet.

The slow fuzes did not in this case appear to have any great advantage, though to a spectator they seemed more efficient.

Experiment II. Breaching caponier.

The caponier (fig. 12, Pl. XII, and Pl. XV) breached in experiment II could not be seen at the battery, and the guns used had to fire down the ditch of the counterguard (C fig. 1) in front of bastion V. Pl. XV, shews the result of the firing, and gives particulars as to range, &c. The experiment was to test the practicability of breaching the caponier with 12 C.M. and short 15 C.M. guns, and to try the 21 C.M. rifled howitzer against the roof.

The two guns fired, altogether, about 21 rounds: the first six shots failed to hit; after which each gun made 4 hits; those to the left of the breach being from the 15 C.M. gun. The first hit from the 12 C.M. gun was in *i* 7; the next 3 hits, with one from the 21 C.M. howitzer, formed the breach (Pl. XV) through which several shells from the 12 C.M. gun afterwards passed into the caponier.

With regard to the howitzer, the range was 1670 yds.; angle of elevation, 30°;

charge, 3·2 lbs.; final velocity, 396 feet. Ten rounds were fired: number 6 struck the caponier in the rectangle *i* 2, and the 7th and 8th struck the roof at the cordon, cracking, but failing to pierce, the arch ring. The shells that fell short, made a crater in the ground of about 7ft. by 6ft. by 2ft. 3in. deep (a good double rifle pit).

Experiment III. Long 15 C.M. Guns. The penetration, at a short range, of the long 15 C.M. coil gun, was tried against the left face of bastion IV under the following conditions, viz.:—Charge from 8·6 to 13·6 lbs. of prismatic powder, burster, 5·2 lbs.; range, 187 yards; horizontal angle of line of fire, 67°; angle of descent, 4° to 5°; velocities on impact, 1155, 1320, 1485, and 1534 feet.—Number of rounds, 34.

A diagram of the target, and sections of the wall are given (figs. 11, 10, and 9, Pl. XII), while Table III supplies the other particulars.

The rounds, up to No. 15, were separate hits; so that the penetrations of blind shells and those with bursters can be compared.

Twenty rounds failed to cut through to the earth backing (fig. 9.)

One result of these experiments appears to be, that the shells fired with high velocities did not give much increased penetration, as they were apt to break up before they had penetrated as fully as they might, had they been stronger.

Experiment IV. Breaching of right face of Bastion IV. This breach was formed on the old system of first cutting a horizontal cut through the masonry half the way up, and then two vertical cuts at the ends (D fig. 1.)

The revetment was not visible from the battery, the level of which was about the same as that of the central horizontal division on the target, but the parapet could be seen, and the centre of the target was indicated by a plank in the parapet, which, however, was not a much better mark than a shell crater would have been. The battery was armed with new short 15 C.M. guns, fired with charges of 3·3 lbs., and with bursters of 4·2 lbs. The firing took place down the ditch of the left face of ravelin III, over the crest of the glacis, which was here 198 yards from, and about 8¼ ft. above the cordon of the revetment to be breached; or a drop of $\frac{1}{25}$th to the centre of the revetment.

Two guns were told off for the left, and two for the right half of the breach, the supposed section and plan of the revetment are given in figs. 2 and 3, Pl. XII; they were not, however, found to be very accurate.

The heliotypes (Pls. XIII and XIV) shew the actual state of the breach in two stages, while below them are given the particulars of range, &c., &c.

The work of cutting the horizontal groove progressed up to the 300th round, which, it had been thought, might have completed the breach; Pl. XIII shews the state of the breach at this point, the maximum penetration being so far 8¼ feet.

Up to the 500th round, 456 shells struck and the groove was 56 feet long and 12 feet wide, on the face of the wall. After the 620th round, the horizontal groove was so completely cut through, that about half the shells burst in the earth behind. Two guns were then told off to the right and two to the left vertical groove.

The left half of the wall came down after the 674th round (tearing away from the counter-arch) and the right half, after the 680th round; thus forming a breach in the face of the wall, about 66 feet wide; but with the earth backing and the remains of a counter arch standing almost vertical, so that a further shelling of the earth would have been required to make the breach practicable.

Experiment V. Breach in Ravelin III. The fifth experiment was the breaching of the right face of Ravelin III.

In this case, as in the next, the method of forming the breach was to commence cutting down the wall from the cordon, and to form a ramp up to the breach, by bursting shells in the earth parapet; the mass of the ramp being of earth instead of masonry.

The horizontal angle, made by the line of fire with the face of the wall, was here more than 2° less than 60°, which has been thought to be the extreme limit for long shells, but no shells glanced off the wall.*

A section of the ditch is given (fig. 13, Pl. XII). A ramp, about 30 feet wide, was cut through the glacis to a depth of 6 feet below its crest, and down to the covered way; in order to secure the carrying out of the experiment. The battery was in this case on a site the level of which was such that the ground fell from the breach at an angle (*angle of terrain*) of $1\frac{1}{2}$°.

The target had 30 vertical, and 8 horizontal divisions of one metre each.

In the first day's firing, rounds 1 to 7 missed; in 40 rounds there were 17 hits, 9 over and 14 under. Up to 80 rounds, 37 shots struck. The state of things after the 120th round is shewn in Pl. XVI, and the results of the second and third days' firing in Pls. XVII and XVIII; while the plan of the breach is given for the second and third days in fig. 4, Pl. XII, and the section of the latter by the dotted line A B, Fig. 13.

It will be seen that at the end of the second day's firing, the revetment was cut down to about 11·5 feet below the cordon, and the neck of the breach was about 17 feet wide, and could be ascended without much difficulty; the mean slope being about $\frac{1}{1\cdot34}$; while after the third day's firing, the mean slope was little over $\frac{1}{2}$, and the neck of the breach about 24 feet wide. The chief defect of this breach and of that in ravelin IV, was the small depth of earth (in this case only 18 in.) which covered the brickwork in the neck of the breach, and which would have been trodden away by the passage of bodies of men.

Experiment VI. Breach in ravelin IV. The sixth experiment consisted of the breaching of ravelin IV, the revetments of which were similar to those of No. III. It was carried out with two new bronze B.L. 21 C.M. howitzers ($8\frac{1}{4}$ in.), of 8 calibres, fired with a charge of 9·9 lbs. One of these howitzers had Krupp's cylindro-prismatic breech closer, and Broadwell rings. The other had a different arrangement, with copper rings. Slow percussion fuzes, which explode one second after striking, were also used. The experiment was otherwise similar to

* It may be mentioned that at the siege of Soissons (War of 1870-71) a breach is said to have been made in a revetment that could be seen from the battery; the horizontal angle of fire being only 45°, the range 2300 yards, and the guns being long 15 C.M. guns, with a charge of 5·5 lbs., and the ordinary shells.

experiment V., except that the parapet above the breach had a bonnette (fig. 15, Pl. XII). The horizontal angle of fire was slightly more favourable, and the range and angle of descent rather greater. In this case the breaching of the revetment was carried down to about 13 feet below the cordon. Pl. XIX.

Pl. XX shews the complete breach formed by 132 hits. The width of the neck of the breach at the face of the revetment being about 25 feet, and the earth of the parapet being cut through to the interior slope (fig. 15, Pl. XII), so that the breaches may be taken as fairly similar, and the efficiency of the 21 C.M. howitzer, as compared with that of the 15 C.M. gun, for breaching purposes under similar circumstances, as—

$$336 : 132 \text{ or as } 2\tfrac{1}{2} : 1$$

Result of experiments. Formation of breaches.

(1.) The method of breaching from the cordon downwards seems to have great advantages over that of the horizontal groove. It is evidently much easier and more certain when the effects cannot be seen, or are only partly observed, or in cases when, owing to the narrowness of ditches, &c., &c., there is a difficulty in reaching the lower parts of the wall. Again, the revetment is attacked at the thinnest part of its section, and where it is most easily cut through. It is true that the breaches (Pls. XVIII and XX) are much narrower than that in Pl. XIV; but they have been formed with much less expenditure of ammunition, and under conditions of greater difficulty, owing to the obliquity of the fire and the narrowness of the ditches. They are, moreover, in a more complete state, as well as being capable of any amount of extension.

Relative efficiency of different guns.

(2.) Experiments I and II shew that for close breaching, or against walls such as that of the caponier (fig. 12, Pl. XII), the strengthened 12 C.M. gun, with large charges, will do the work of the 15 C.M. gun very fairly, and might be used for the close attack.

From Tables II and III, we see that the penetration of the shell of the 15 C.M. coil gun, with charges of about $10\frac{1}{2}$ lbs., was only about 3 ft.; while that of the short 15 C.M. gun, with a charge of only 2·9 lbs., was nearly 2 ft. in these revetments.

The comparative efficiency of the short 15 C.M. gun, and of the 21 C.M. howitzer, appears to be as 1 to 2 or $2\frac{1}{2}$ for breaching purposes.

Obliquity of fire.

(3.) With regard to the amount of obliquity that is admissible, experiment V shews that shells penetrate on striking at horizontal angles as small as $57\frac{3}{4}°$ with the face of the masonry.

Use of slow fuzes.

4. The slow fuzes do not on the whole seem to give any very great advantage in masonry, though they do with earth, as far as could be judged by sight.

Method of laying guns.

The guns were laid by trial shots; a hit having been made, the point of impact was transferred, as required, by using calculated tables. The guns were directed by means of the new laying scales, which consist of two metal plates graduated on each side of the Zero, which corresponds with the axis of the piece; one scale hangs down below the axle, and the other between the brackets of the carriage at the trail, each with the lower edges close to the platform (fig. 4, Pl. XII).

When the right direction is decided on, a brass plate is screwed to the horizontal platform under each scale, with a mark on it corresponding to the zero.

When the gun is to be relaid, the two zeros are again brought over the marks on the brass plates, or, to save cross-lifting, the same division to the right or left of zero on each scale is made to correspond with the mark on its brass plate; by this means the axis of the piece is kept in the same line, or in one parallel to it, which practically answers as well. Any further change of direction can be read off on the two scales and repeated at will. The method of getting the elevation is by a quadrant, and is very rough, but seems to answer.

Indications in Breaching. The noise of impact on masonry is sharp: when the wall is cut through, the sound is dull. The same is the case when a shell strikes earth. The deeper the penetration in masonry, the longer the smoke takes to rise. Till the wall is cut through, the smoke is bluish-white or red with brick dust. When shells burst in the earth behind a revetment which has been cut through, the smoke is dark grey, and rises as out of a chimney. At Graudenz splinters were observed to come back at least 400 yards from the masonry.

T. F.

TABLE I.

No. of Round.	Charge (Kilos.)	Nature of Projectile of strengthened 12 C.M. gun.	Point of impact. Above bottom of ditch.	Point of impact. Right or left of centre.	Size of hole. Depth.	Size of hole. Breadth.	Size of hole. Height.	Behaviour of Projectile.	Remarks.
			metres.	metres.	feet.	feet.	feet.		
2	1·5	Plugged......	4·7	0·1R	1·3	1·9	2·0	Stuck.	Measured to bottom of shell. Length of shell 11·8 ins.
4	,,	,,	4·7	0·9R	1·3	1·7	2·0	,,	
6	,,	Live shell with slow fuze ...	3·0	0·1L	2·2	2·6	2·2	Burst.	
8	,,		3·0	0·4R	2·5	3·7	3·4	,,	The whole depth of the penetration is measured.
10	,,	Live shell, ordinary fuze	4·6	2·1L	2·5	3·2	3·7	,,	
12	,,		4·1	3·0R	2·9	3·9	3·4	,,	
14	,,	Live shell, slow fuze	6·3	2·6L	2·6	3·3	3·2	,,	
16 to	,,	Live shells with ordinary fuze	5·7	0·8R	2·5	3·3	2·8	,,	The wall between 16 and 4 is loosened.
26	,,		..	..	4·6	11·2	5·1	1 shell blind, 9 burst.	The brickwork broken through for 3 ft. Rubble visible.
36 to	,,	do.	..	..	5·4	18·7	5·3	Burst.	Height of rubbish and rubble in the hole about 18 ins.
46	,,	do.	..	..	7·8	,,	,,	Do.	Rubbish in hole about 18 ins. high.
52 to	,,		..	..	9·7	,,	,,	Do.	Penetrated through brick and rubble to sand.
58	,,	Live shell with slow fuze ..	..	..	8·2	,,	5·6	Do.	A quantity of rubbish and stones in the hole; not possible to measure greatest depth of hole.

TABLE II.

No. of Round.	Charge (kilos.)	Nature of Projectile of short 15 C. M. Gun.	Point of impact. Above bottom of ditch.	Point of impact. To right of centre.	Size of hole. Depth.	Size of hole. Breadth.	Size of hole. Height.	Behaviour of Shell.	Remarks.
			metres.	metres.	feet.	feet.	feet.		
1	1·5	Plugged......	4·7	5·8	1·0	2·2	2·15	Stuck.	Measured to bottom of shell. Length of shell 11·8 inches.
3	1·0	do.	4·5	5·0	1·9	2·1	2·4	Fell in the ditch.	The entire penetration measured.
5	1·5	Live shell, slow fuze.........	3·0	6·0	2·2	4·7	4·7	Burst.	
7	1·0	do.	2·7	4·2	1·7	2·15	2·4	,,	
9	1·5	Live shell, ordinary fuze.	4·4	7·6	2·4	3·6	4·2	,,	
11	1·0	do.	2·7	8·6	1·8	3·8	3·5	,,	
13	1·5	Live shell, slow fuze...........	5·9	7·5	2·15	3·8	3·1	,,	Wall between divisions 13, and 9 loosened.
15	1·5	Live shell, ordinary fuze.	4·8	9·5	2·4	3·6	3·7	,,	

TABLE III.

No. of Round.	Charge, prismatic powder.	Velocity on impact.	Nature of Projectile of long 15 C. M. Gun.	Point of impact. Above Ditch.	Point of impact. To right or left of centre.	Size of hole made by shell. Depth.	Size of hole made by shell. Breadth.	Size of hole made by shell. Height.	Behaviour of Projectile.	Remarks.
	kilos.	feet.		metres.	metres.	feet.	feet.	feet.		
1	3·9	1148	Long shells fully charged, and with ordinary fuzes with spirals.	5·6	0·3 L	3·4	3·7 up to No. 3	4·3	Burst.	
2	4·9	1312		5·5	1·5 R	3·3		4·4	do.	
3	5·95	1476		6·0	3·5 R	2·8	do.	5·1	do.	
4	6·2	1525		5·6	7·7 R	3·5	do.	5·0	do.	
5	3·9	1148	Shells filled with peas.	5·85	9·7 R	*1·8	2·8	3·4	do.	* Measured to the bottom of shells.
6	4·9	1312		6·0	11·7 R	*2·2	2·7	3·4	do.	* Ditto; length of shell 11·8 inches.
7	5·95	1476		5·9	13·0 R	3·4	4	3·8	Split up.	
8	6·2	1525		3·6	2·8 L	3·1	3·7	3·3	do.	
9	3·9	1148	Long shells fully charged, and with slow fuzes, with spirals.	3·8	0·1 L	3·2	5	3·3	Burst.	Measured to the top of the cavity in the point of shell.
10	4·9	1312		4·0	2·5 R	3·3	4·7	4·1	do.	
11	5·95	1476		4·2	5·4 R	3·1	4·9	5·0	do.	
12	6·2	1525		6·1	3·3 L	3·7	6·1	5·5	do.	
13	6·2	1525	Long shells with time fuzes.	5·5	5·4 L	3·2	4·8	4·6	do.	
14	3·9	1148		...	...	3·1	5·8	5·3	do.	
15 to 24	6·2	1525		...	...	5·6	19·8	6·8	do.	There was a quantity of rubbish in the cut. Height of rubbish at foot of wall 3 feet.
25 to 34	6·2	1525		...	...	8·1	...	8·6	do.	Height of rubbish at foot of wall 5 feet.

PL.XII.

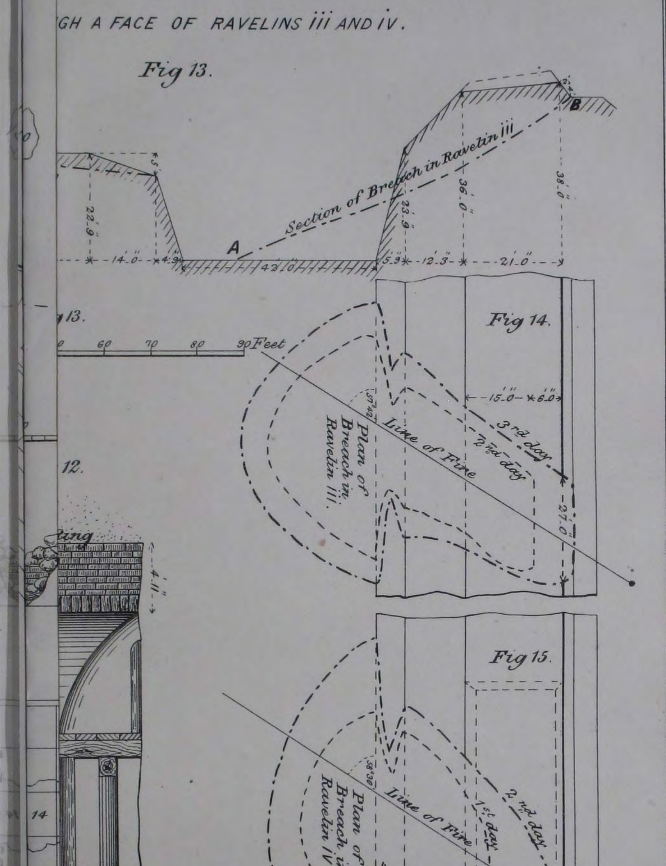

GH A FACE OF RAVELINS iii AND iv.
Fig 13.
Section of Breach in Ravelin iii
A
B
22.9"
14.0"
4.9
42.0"
5.3"
12.3"
21.0"
23.9"
36.0"
38.0"
Fig 14.
60
70
80
90 Feet
15.0"
6.0"
3rd day
2nd day
Line of Fire
Plan of Breach in Ravelin iii.
27.0"
12.
4.11"
Fig 15.
Plan of Breach in Ravelin iv
Line of Fire
1st day
2nd day
10.0"
14

Plate XIII.

HELIOTYPE. S.M.E

BREACH IN RIGHT FACE OF BASTION IV. MADE BY SHORT 15 C.M. GUNS.

RANGE 800 YDS. — HORIZONTAL ANGLE OF FIRE 75° — ANGLE OF DESCENT 4° — FINAL VELOCITY 775 FT.

FIRST 3 DAYS FIRING, ... ROUNDS 300 — HITS 274 — {INCLUDING 2 EARTHS}

HELIOTYPE . S.M.E.

BREACH IN RIGHT FACE OF BASTION IV. MADE BY SHORT 15 C.M. GUNS.
RANGE 800 YDS — HORIZONTAL ANGLE OF FIRE 75° — ANGLE OF DESCENT 4° — FINAL VELOCITY 775. FT.
TOTAL NUMBER OF ROUNDS FIRED 684 — HITS 624 — { INCLUDING 36 EARTHS }.

Plate XIV.

Plate. XV.

Heliotype. S.M.E.

Breach made in a Caponier at a Range of 1496 Yds.

For 12 C.M. Guns. – Angle of Descent $5\frac{12}{16}°$. – Final Velocity 1060 Ft. – Hits, 32.
For 15 C.M. Guns. – Angle of Descent $7\frac{9}{16}°$. – Final Velocity 736 Ft. – Hits, 4.

Plate. XVI.

HELIOTYPE. S.M.E.

BREACH IN RIGHT FACE OF RAVELIN III MADE BY SHORT 15 c.m. GUNS.

RANGE 1155 YDS. — HORIZONTAL ANGLE OF FIRE 57°42′ — ANGLE OF DESCENT 7° — FINAL VELOCITY 673 FT.

FIRST DAY. ROUNDS 120 — HITS 58 — VIZ, {1 EARTH, 1 CORDON, 56 WALL.}

Plate XVII.

HELIOTYPE. S.M.E.

BREACH IN RIGHT FACE OF RAVELIN, III. MADE BY SHORT 15 C.M. GUNS.

RANGE 1155 YDS.——— HORIZONTAL ANGLE OF FIRE 57°. 42'.—ANGLE OF DESCENT 7°.—FINAL VELOCITY 673 FT.

SECOND DAY.—. ROUNDS 360.——— HITS 224, {VIZ. 46 EARTH — 1 CORDON — 177 WALL}

Plate XVIII.

HELIOTYPE S.M.E.

BREACH IN RIGHT FACE OF RAVELIN, III, WITH 15 C.M. GUNS.

RANGE 1155 YDS.— HORIZONTAL ANGLE OF FIRE 57°42′— ANGLE OF DESCENT 7°— FINAL VELOCITY 673 FT.

THIRD DAY.— ROUNDS 484 — HITS 336 {VIZ— 124 EARTH — 1 CORDON — 211 WALL}

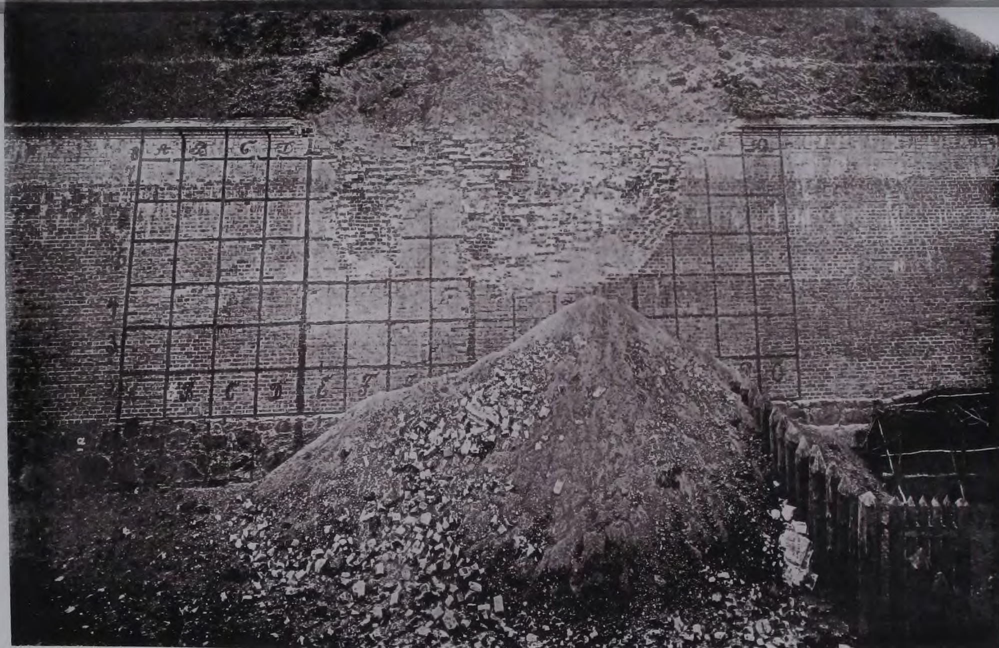


Plate. XIX.

HELIOTYPE S.M.E. BREACH IN RIGHT FACE OF RAVELIN IV. WITH 21 C.M. HOWITZERS.

RANGE 1171 YDS — HORIZONTAL ANGLE OF FIRE 58°30'. — ANGLE OF DESCENT $6\frac{10}{11}$° — FINAL VELOCITY 705 FT.

FIRST DAY. ROUNDS 80. — HITS 46. { VIZ, 19 EARTH, 3 CORDON, 24 WALL. }

Plate.XX.

HELIOTYPE. S.M.E

BREACH IN RIGHT FACE OF RAVELIN IV. WITH 21 C.M. HOWITZERS.

RANGE 1111 YDS. – HORIZONTAL ANGLE OF FIRE 58°30'. – ANGLE OF DESCENT 6 10/16°. – FINAL VELOCITY 705 FT.

SECOND DAY. ROUNDS 190 – HITS 132, {VIZ. 59 EARTH, 3 CORDON, 70 WALL.}

PAPER VI.

DESCRIPTION OF ROYAL ENGINEER INSTITUTE, CHATHAM.

BY MAJOR MARSH, R.E.

The Corps at large, and especially those members of it who have been stationed at, or taken special interest in, the School of Military Engineering at Chatham, during the last few years, will learn with satisfaction that the Royal Engineer Institute is on the point of completion and occupation. (March, 1874.)

With the exception of the change of site of the Field Work Depôt, in 1868, when, in consequence of the Dockyard extensions on St. Mary's Island, it was moved up to the ground adjoining the observatory—absorbing Uncle Tom's Cabin and Prince Frederic's Bastion, with the adjoining curtain and ditches—no such radical change has yet taken place in the familiar precincts of Brompton Barracks, as the substitution of this handsome and capacious building for the barrack rooms and scattered auxiliary buildings in which the studies of both the officers and men of the Corps have been hitherto conducted.

The increasing pressure on the teaching power and accommodation of the school, caused by the wants of India, the augmentations of the Corps, and the extension of the educational advantages of the Engineers to selected classes of officers and non-commissioned officers of the other branches of the service, was fully ventilated by the Royal Commission on Military Education of 1869, of which Lord Northbrooke was chairman; and, on the recommendation of that Commission, a vote of £21,000 was taken in 1871 for the erection of a building to accommodate the whole of the class-rooms, laboratories, lecture theatre, and other wants of the instructional staff. A Royal Engineer committee, composed of Lieut. General Sir Lintorn Simmons, K.C.B., Major General Sir Henry Harness, K.C.B., and Colonel Gallwey, Commandant of the School of Military Engineering, drew up the general conditions as to floor space, and proposed a site in the Hut Barracks for the Institute, the design for which was then prepared at the War Office, under the direction of the Inspector General of Fortifications, Lieut. General Sir Frederick Chapman, K.C.B., by Lieutenant Ommanney, R.E., the Fowke medallist of 1872.

Tenders for the execution of the contract were called for by the Commanding Royal Engineer, Colonel Lovell, C.B., and accepted in November, 1871, and on 28th May, 1872, the foundation stone was laid by H.R.H. the Field Marshal Commanding-in-Chief.

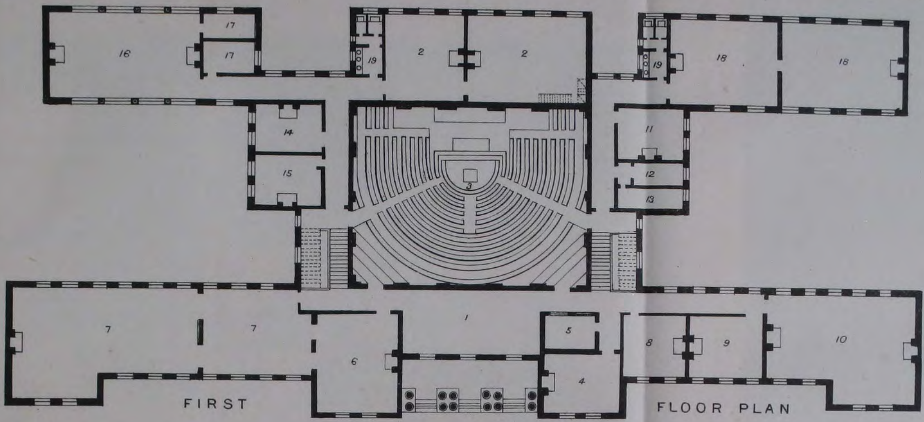
The building stands in the Hut Barracks enclosure, facing west on Brompton Barracks, and centering with the memorial arch and the barrack clock. The site is four feet below the barrack parade, but the whole of the ground line in front of the new building is raised to the parade level, sloping down to the road to St. Mary's Barracks: thus the bottom of the steps leading to the Institute portico is on the level of the pavement of Brompton Barracks; the drainage facilities of the site are much improved; and, moreover, if desired hereafter, the barrack parade might be extended up to the Institute.

The foundations, of Thames ballast and blue lias lime, rest upon the sands and loams of the plastic clay series immediately overlying the chalk. The buildings are Italian in style, the details of the main front being somewhat freely treated, in order to give scope for the employment of terra cotta instead of stone in the whole of the ornamental work, except the upper members of the cornices and the columns of the entrance. They consist of a front and rear range, connected by a central block, so that the buildings enclose between them two courts, on which open the rear entrances to the class rooms, lecture theatre, &c. The general arrangements are as follows:—The first floors, front and rear, are occupied by the instructors' rooms and officers' halls of study; the ground floor, front and rear, by the assistant instructors and the halls of study for the non-commissioned officers and men. There is a half basement to the front range, containing the laboratory and the schools for printing and lithography; the library and museums, and the offices of the Engineer committee, are in the north wing of the front range. The accommodation for photography is in rear, including a printing gallery on the roof. The appropriation of the rooms is fully given on the accompanying drawings, Pls. XXI, XXII, and XXIII.

The buildings are executed in brickwork, with cornices in Portland stone and terra cotta, the latter material being largely used on the west front in ornamental friezes, string courses, balusters of roof and terminals. The Corinthian columns on the first floor, over the west portico, are of Portland stone, with capitals of terra cotta; the spandrils and keystones of the three doorways of the portico are in highly ornamented terra cotta, and were exhibited at the Vienna Exhibition of 1873, by the contractors for the supply of the terra cotta, Messrs. Doulton, of Lambeth. Original drawings to scale, were furnished by Lieutenant Ommanney for all these details, and the heliotypes (Abney's process) annexed, will illustrate the ability and care bestowed upon the design.

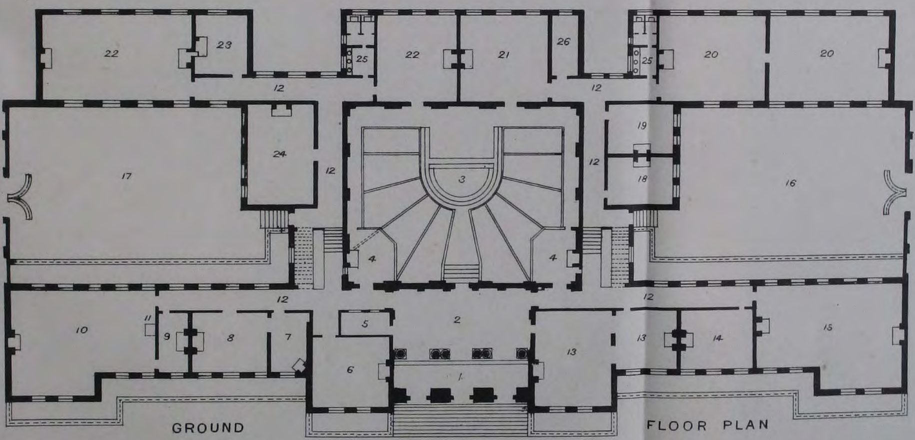
The front building, up to the first floor, is faced with Suffolk bricks, every fifth course being of terra cotta dentils; yellow malms are used above the first floor, giving a contrast with the terra cotta and Suffolk bricks; all other portions of the buildings are faced with yellow malms; the chimney stacks are in Portland stone. Major General Scott's selenitic mortar has been used throughout, with excellent results, that in the body of the work being six of sand to one of pre-

THE ROYAL ENGINEER INSTITUTE, CHATHAM.



REFERENCES TO FIRST FLOOR PLAN

1. *Gallery.*
2. *Photography.*
3. *Lecture Theatre.*
4. *Draughtsmen.*
5. *Messenger.*
6. *Museum for Inventions.*
7. *Museum.*
8. *Testing room.*
9. *Construction Instructor.*
10. *Construction: Officer's Hall of Study.*
11. *Survey Instructor.*
12. *Survey Instructor's Store.*
13. *Survey Messenger.*
14. *Instructor.*
15. *Assistant Instructor.*
16. *Glass house.*
17. *Dark rooms.*
18. *Survey: Officers' Halls of Study.*
19. *Lavatories &c.*



SCALE OF 10 5 0 10 20 30 40 50 60 70 FEET

REFERENCES TO GROUND FLOOR PLAN.

1. *Vestibule.*
2. *Hall.*
3. *Lecture Theatre.*
4. *Retiring rooms.*
5. *Messenger.*
6. *R.E. Committee.*
7. *Secretary.*
8. *Clerks.*
9. *Librarian.*
10. *Library.*
11. *Gurney stove.*
12. *Corridor.*
13. *Construction: Model rooms.*
14. *Construction: Assistant Instructor.*
15. *Construction: Men's Hall of Study.*
16. *South Court, Construction: Survey. and Signalling.*
17. *North Court: Telegraphy and Photography.*
18. *Survey: Assistant Instructor.*
19. *Signalling: Assistant Instructor.*
20. *Survey: Men's Halls of Study.*
21. *Signalling.*
22. *Telegraphy.*
23. *Instructor.*
24. *Drawing Room.*
25. *Lavatories &c.*
26. *Store.*

THOS KELL, LITH. 40, KING STREET, COVENT GARDEN.

Plate. XXIII

HELIOTYPE. S.M.E.

ROYAL ENGINEER INSTITUTE.

Plate XXIII

HELIOTYPE . S.M.E.

DETAIL OF TERRA COTTA WORK.

pared lime, and the joints being struck with four of sand to one of lime; the rendering of the walls and the plastering of the ceilings is also done with selenitic lime.

The rooms are warmed and ventilated with the barrack ventilating grates and up-cast shafts, except the lecture theatre, in which are two of Gurney's ventilating stoves under the platform. Gas is laid on throughout the buildings, with a sun-light in the theatre.

Due respect for tradition was paid in laying the foundation stone. A leaden box, eighteen inches square and six inches deep, sunk in the stone, was filled with all the printed forms in use and well known course-books of the school; Pasley, on Limes and Cements; Jebb, on the Defence of Posts; the Manual on Field Works; Notes on Astronomy and Construction; these were carefully soldered up in the presence of His Royal Highness. Let no one hastily conclude that such solemn interment meant other than the conviction that some day in the far future they will reappear to remind the Corps standard-bearers of those days that the foundations of English Military Engineer training were laid true to square and plummet, and had remained unshaken by the ever increasing superstructure that a wider knowledge had laid upon them. The same receptacle also contains maps of the Dockyard extensions, and of the War Department property of the district, with photographs, and copies of Punch and the daily papers.

The contractor for the execution of the buildings is Mr. George Sollitt, of Strood; the terra cotta being supplied by Messrs. Doulton, of Lambeth. The total cost, exclusive of library and museum fittings, will be £21,000.

It is reasonable to conjecture that advanced study in the corps will receive an impetus from such considerable increase of accommodation, and that a wider diffusion may be looked for of the special knowledge on professional subjects elaborated from time to time at Chatham.

The attention of all officers is invited to the proposed museums, contributions for which have been requested by the Commandant, Colonel Gallwey, in the R.E. Journal for November, 1873.

W. D. M.

PAPER VII.

THE SCALE OF SHADE SIMPLIFIED.*

By CAPTAIN J. A. MILLAR, R.E.

When the writer of this Paper was at the Royal Military Academy about sixteen years ago, the only distinct rule taught as to the shading of ground, except the rules relating to evenness of stroke and to the lengthening or shortening of the hâchures necessary in working round curved features, was this—that the shading must be darkest towards the top of the hills, and lighter towards the bottom.

One or two other rules were gradually formed in the mind of the cadet from a course of mechanical copying of examples of hill shading, but probably few of the cadets could have expressed them in words. These rules would be something like the following :—

1st. No considerable mass of hâchures can disappear or die out except by returning into itself like a ring, or by passing over the edge of the drawing, or by ending in a cliff or precipice.

2nd. No set of hâchures must cross another set, or run into them transversely or obliquely.

By continued study and copying of examples, the pupil gradually learned to express simple forms of hills and valleys, and to copy plans neatly and with facility; but the writer's impression is, that only a very few cadets were, at the end of their course, capable of sketching, by rule of thumb, a piece of ground with any approach to accuracy. There was, however, no examination in the subject to test their proficiency.

The great improvement which has taken place in the teaching of military drawing during the last ten years, is due to the Military Education Authorities, but more especially to Major General H. Y. D. Scott, R.E., who is the author of a paper read at Chatham, in February, 1863, and afterwards published in the Royal Engineer Corps Papers, Vol. XII., which gives a very interesting history and a most useful exposition of the subject, written with great clearness. The establishment of a Department of Military Education, to which the Military Colleges are subject, gave an excellent opportunity of reducing to unity the various methods of representing ground in military surveys, and the scale of shade advocated by Major General Scott, was recognised by the Military Education Authorities as well suited to supply the required standard for the military draughtsman.

* This Paper was read at an Occasional Meeting held at the War Office, on the 28th May, 1874. The short-hand writer's notes of the discussion will be found printed at the end of the volume.

It is not intended in this paper to enter deeply into the question, whether a scale of shade is desirable or not; but the writer is convinced, by his experience, that for educational purposes a scale of shade is very necessary.

In teaching officers, who are naturally less pliant and tractable than young cadets, great difficulty has been found in getting them to adhere with reasonable accuracy to the authorised scale of shade. They may commence with the best intentions, but, as the slopes are constantly changing, the thickness of the strokes and the distances between them have to be continually modified, and very few have the patience and perseverance to carry through accurately such minute and tedious work.

Major General Scott's scale, as given in the Official Manual, has eight different thicknesses of stroke or hâchure, varying from $\frac{1}{50}$th to $\frac{1}{400}$th of an inch. Some of these differ very little in thickness, as for instance those of $\frac{1}{90}$th and $\frac{1}{110}$th of an inch in width. Suppose one of these two strokes drawn on paper. Is there one officer in fifty, however well trained, who could tell, without referring to the scale, which of the two hâchures was before him?

When we consider the difficulties arising in actual practice, from bad pens, thick ink, and greasy, coarse, or damp paper, the task of representing these delicate gradations of stroke becomes exceedingly difficult.

It is proposed in this paper to simplify matters by reducing the number of thicknesses of stroke to three—the thick, the medium, and the thin. See Pl. XXIV.

The thick stroke is $\frac{1}{50}$th of an inch in width, the medium $\frac{1}{100}$th, and the thin $\frac{1}{200}$th of an inch. As each stroke is twice as thick as the next thinner, their relative thicknesses can be easily judged, and there can be no danger of mistaking one for the other. The absolute thickness of the hâchures may be varied a little, without a chance of a mistake as to the slopes intended, provided sufficient distinction is made between the three orders of thickness.

Each thick stroke, with its adjacent white space, represents as much vertical rise or fall as two medium or four thin strokes and spaces.

Thus, a thin stroke and space represent a rise of 4 ft. 2 in. (the 12th part of 50 ft.); a medium stroke and space, 8 ft. 4 in.; a thick stroke and space, 16 ft. 8 in.; or, roughly, 4, 8, and 16 ft. respectively.

Between the fifty feet contours there are, therefore, three black strokes with as many spaces, or six medium strokes and spaces, or twelve thin strokes and spaces.

This scale of shade is extremely easy to construct, as follows:—Divide an inch into seven equal parts with the compasses, and mark off a space equal to two of the sevenths.

To obtain the proper shade for any number of degrees under ten, divide the $\frac{2}{7}$ths of an inch into as many parts as there are degrees, the divisions being thin strokes.

From 10 deg. upwards and under 20 deg., the spaces are half as many as the degrees, and the strokes of medium thickness or twice as thick as before.

From 20 deg. upwards thick strokes are used, and the number *per inch* is the same as the number of degrees, except for the slope of 20 deg., which has five strokes in $\frac{2}{7}$ths of an inch.

The following considerations facilitate the shading of the steeper slopes :—

At 25 deg. the light and shade are equal, the white space being equal in breadth to the dark.

At 20 deg. the white space is double the dark.

At 35 deg. the dark space is double the light.

By dividing an inch into 25 parts and thickening the divisions until the lights and darks seem equal, the proper thick stroke may be obtained, and the others may be obtained from it by estimation.

The following advantages are claimed for this system :—

1st. There is a considerable saving of time in shading, by the new scale, a contoured plan, as it is not necessary to keep continually applying the scale as in the present system. Indeed, after the shading is once commenced, the scale is scarcely required, except to determine at what points the thick strokes are to be replaced by thinner ones, and *vice versa*, viz., where the slope changes from above 10 deg. to below 10 deg., or from above 20 deg. to below 20 deg. In this case each stroke must be exchanged for two strokes of half the former thickness.

2nd. The difficulty of making eight different sorts of strokes is removed by the number being reduced to three, of very different thicknesses.

3rd. Whatever difference of appearance there may be between drawings executed by the old and new scales of shade, is to the advantage of the latter. This is shewn by the example attached, which is more forcible in style than the corresponding example hâchured according to the established scale. See Pl. XXV.

In the examples of each method the object has been, not so much to produce a perfect specimen of hill shading, as to give a fair representation of the effect of the two methods, the merits of the drawing, in other respects, being as nearly as possible equal. On this account a certain rigidness and stiffness, which may be noticed in the examples, has been tolerated, in order to allow of the scales being applied with more exactness.

4th. The slopes are easier to distinguish, as the thin strokes, where they appear, shew at once that the slope is under 10 deg. ; the medium, that the slope of the ground is between 10 deg. and 20 deg. ; and the thick, that the slope is 20 deg. or upwards.

The darker shades can be immediately recognised by comparing the proportion of light and shade, remembering that at 25 deg. the light and shade are equal.

5th. In teaching, it is a great advantage to be able to attach a definite meaning to the hâchures.

Thus each thin hâchure and space represent a rise or fall of about 4 feet, a medium stroke and space 8 feet, and a thick stroke and space 16 feet. The exact numbers to suit the 50 feet contour are $4\frac{1}{6}$ feet, $8\frac{1}{3}$ feet, $16\frac{2}{3}$ feet.

6th. The new scale of shade can be drawn easily in a few minutes, without micrometric measurement, and all its details can be carried easily in the memory.

The writer would be very sorry to suggest any change in an established scale —as changes so often cause inconvenience—were it not that experience in the teaching of military drawing during more than three years has convinced him that some simplification of the scale is extremely desirable. He has also formed

PROPOSED SIMPLIFIED SCALE OF SHADE.

SLOPE IN DEGREES	TANGENTS OR RISE IN 100 FEET HORIZONTAL	THICKNESS OF STROKE	NUMBER OF STROKES PER INCH	Nº IN $\frac{2}{7}$ INCH	PROPORTION OF LIGHT TO SHADE	EQUIVALENT OF 50 FEET CONTOUR FOR SCALE OF 6 INCHES TO ONE MILE
35°	70	$\frac{1}{50}$	35	10	1 to 2	Strokes & Spaces 3
30°	58	$\frac{1}{50}$	30	$8\frac{1}{2}$	2 to 3	" 3
25°	46	$\frac{1}{50}$	25	7	1 to 1	" 3
20°	36	$\frac{1}{50}$	$17\frac{1}{2}$	5	2 to 1	" 3
18°	32	$\frac{1}{100}$	30	9		" 6
15°	27	$\frac{1}{100}$	25	$7\frac{1}{2}$		" 6
10°	18	$\frac{1}{100}$	$17\frac{1}{2}$	5		" 6
8°	14	$\frac{1}{200}$	28	8		" 12
6°	$10\frac{1}{2}$	$\frac{1}{200}$	21	6		" 12
4°	7	$\frac{1}{200}$	14	4		" 12
2°	$3\frac{1}{2}$	$\frac{1}{200}$	7	2		" 12

Thoˢ Kell Lith. 40 King St. Covent Garden

a strong opinion that hâchuring ought always to be based upon contours, however few and rough they may be. If a man cannot express his idea of the form of the ground in a given district by means of contours, it is usually because he has no distinct idea to express.

The examination of a great number of route-marching and reconnaissance sketches by officers of very various attainments, has also strengthened the writer's opinion that hâchuring a sketch without contouring it, leads generally to confusion and inaccuracy.

The practice of contouring is now rendered comparatively easy by the introduction of Major Hutchinson's aneroid, which for ordinary military sketches appears to work well, though change of weather often gives some trouble to those using it.

Abney's pocket level is also a capital instrument for the military sketcher, being unaffected by wind or variations of atmospheric pressure.

The Aldershot protractor, with a plummet, finds little favour with most officers as an instrument for measuring slopes, as it cannot be used when there is any wind, and at any time it is difficult to take a sight along the sharp bevelled edge. The string and plummet get in the way also in the protraction of angles.

If aneroids could be made considerably cheaper than they are at present, they would probably become an indispensable part of the kit of the military sketcher, and contours only would be drawn in the field, the shading being executed under cover, and perhaps mechanically by a clerk or non-commissioned officer.

J. A. M.

PAPER VIII.

EXPERIMENTS ON THE HOLDING POWER OF EARTH AND THE STRENGTH OF MATERIALS.

By LIEUTENANT T. FRASER, R.E.

In connection with the subject of military bridging, a number of experiments have, from time to time, been made, chiefly to get trustworthy information for use in the revision of *Instruction in Military Engineering.* As in that work there is only room for the facts, it has been thought worth while to give detailed accounts for future reference. Accordingly, in Paper XV., of Corps Papers, Vol. XXI., certain results were given, and the present paper (with the tables in the appendix) includes results as to—

1st. The holding power in earth of land ties or anchorages, such as have to be used for bridging.

2nd. The strength and other properties of cordage, and the effects of different modes of fastenings.

3rd. Some experiments as to the strength to resist cross-breaking of green timber as compared with dry.

In Table I. are given the general results of experiments made to test the holding power of surfaces of from $\frac{3}{4}$ square foot to $6\frac{1}{2}$ square feet when buried at different depths, and when acted on by forces varying in direction from the vertical to $\frac{1}{4}$. The surfaces used were those of square, half-round, and round logs. The force was obtained by means of a lever, as described in Paper XV. of Vol. XXI., 1873, and as now shown in figs. 1 and 2, Pl. XXVI.

The accuracy of the calculated leverage was checked both by counterpoising the lever, and also by the use of one or more hydraulic dynamometers in the chains (as at D, fig. 1, Pl. XXVI.) These dynamometers were known to be fairly correct, and all calculations were saved by reading the stresses on their dial-plates.

In those cases where the anchorages were pulled up vertically, the block M, fig. 1, was dispensed with, and the anchor block was buried by cutting as small a hole, in every way, as would just allow it to go down, till its top surface or (in the case of round logs) its axis was at the required depth below the surface. The chains connecting the anchor with the lever were then brought up to the surface, and the earth filled in and rammed.

In other cases, the anchors were placed by cutting trenches for them of the

form shewn in figs. 1 and 2, and by boring inclined holes (A to C and B to D, fig. 2) through the solid earth for the connecting rods or ties. These holes could not be made very small, and to a certain extent, no doubt, diminished the results. When the anchor had been placed, levelled, and set with its face perpendicular to the direction of the pull, the earth was filled in and rammed as in the other cases.

In testing with inclined forces, the change in direction was produced as shewn in figs. 1 and 2, where N is a 12 in. by 12 in. fir block, secured to the beam M by a strap, and furnished with two pulleys at R. The strap prevented the block from rising, and the beam S, (fig 1), which butted against a revetment wall, prevented the tendency to rotate about its outer edge.

Remarks on the experiments.

Most of the experiments were made in the loam of the Royal Engineer park ditch, as, being the most homogeneous available, it was likely to give the most uniform results. For the sake of comparison, other experiments were made in a hard gravelly soil, the quality of which varied somewhat with the depth; in river clay (Medway blue mud); and also in loose unrammed fresh water sand with a little gravel in it.

It should be mentioned that though, when broken up, neither the loam nor gravel has a very high angle of repose, yet, when first cut, each would stand with a vertical face for a considerable height and for a long time. In all the tests, the loads were of necessity increasing in amount, and were applied for a long time, and frequently reapplied.

In order to ascertain to what extent the friction of the surfaces parallel to the pulling force increased the holding power, a spar of 3 ft. 6 in. in length and of a diameter of 10 in., was buried vertically in a hole in the loam filled with rammed earth (fig. 8), the mean depth being 1 ft. 9 in., when it was found that the resistance was only 90 lbs., which is trifling compared with the resistance of the same surface when placed as at B, fig. 1, perpendicular to the pulling force. This seems to show that a square log, at least in rammed earth, would have but little more holding power than a round or half round log, with a diameter equal to the side of the square, that is with the same surface perpendicular to the pulling force: a fact confirmed by some of the experiments in Table I.

The following approximate results appear from Table I:—

1. As to the relative holding power of different earths; the results are stated in Table II.

2. That anchors with the same amount of surface perpendicular to the pulling force have nearly the same resistance, whether square, round, or half-round.

3. That the mean ultimate holding power of loam earth (per square foot of surface perpendicular to the pulling force) as obtained from these experiments, is given in Table III, where the results marked * have been calculated from the experimental results.

Effect of length on holding power.

It appears from experiments 20 to 23, that the holding power per square foot diminishes somewhat as the length increases, owing, no doubt, to the fact that in solid earth the resistance of the ends (which is constant) is a good deal greater than in rammed earth; for this reason in forming Table III., a reduction has been made in the results of experiments 29, 30, and 31.

Effect of width on holding power.

In order to ascertain whether the same result would be obtained with surfaces broader than 1 ft., an anchor of the form shewn in fig. 5, was placed as in fig. 3, so that its surface may be considered as corresponding with the surfaces of three horizontal anchors (as in fig. 4), each 12 in. by 12 in. The result of this experiment is given at No. 34, Table I.

If we consider the surfaces in fig. 4 with reference to Table III., the resistance per square foot would be approximately :—

$$\text{For the 1st, } \frac{1 \text{ ft. } 9 \text{ in.}}{2} \times 2700 \text{ lbs.} = 2363 \text{ lbs.}$$

$$\text{For the 2nd, } \frac{(2700 + 4400)}{2} = 3550 \text{ lbs.}$$

$$\text{For the 3rd, } \frac{3 \text{ ft. } 2 \text{ in.}}{3} \times 4400 = 4644 \text{ lbs.}$$

Making a total of 10557 lbs.

While from experiment 34, the resistance was 3 × 3660 lbs. = 10980 lbs.

From this it appears that the table is applicable to anchorages with wider surfaces than 12 inches, as for instance, in fig. 15, Pl. XI., Paper IV.

Diagram of curves of pressure.

The amount of resistance per square foot of surface, as given in Table III., is shewn graphically in fig. 6,; the numbers 1, 1·5, 2, &c., being the mean depths in feet of the square foot of surface in each case. If the mean depth happen to be intermediate between any of these, as at A, the resistance is represented by AB, the value of which in lbs., can be read off on the scale at the bottom.

Other experiments.

Besides the timber anchors, a 4 ft. length of 9 in. fascine was tried (experiment 15), and was found to give a considerable holding power, viz., 7060 lbs.

Park pickets (3 in.) were also tested, as in fig. 9, at a slope of $\frac{2}{1}$. When driven 1 foot into the ground they drew with $3\frac{1}{2}$ cwt.; at 2 feet down, they stood up to 11 cwt.; and when driven into the ground for a length of 3 ft., failure occurred with 1 ton of pressure, by the picket head breaking off at the ground.

In similar soils, therefore, there is no object in driving such pickets more than between two and three feet.

Tests of Cordage.

The machinery used for testing most of the ropes was the lever already described, the rope or lashing to be tested being inserted between the beam M, and the short end of the lever; screw couplings being used to take in the slack. The elongations of some of the larger hemp, and also of the wire, cables were observed, by permission, in the Testing House, H.M. Dockyard, Chatham.

The information sought was :—

1st. To find the relative strength of certain fastenings, &c., such as a *bend and seizings*, a *clove hitch*, a *reef knot*, a *gasket stopper*, a *timber hitch*, a *transom lashing*, a *Spanish windlass;* also of *eye*, *short* and *long splices*.

2nd. To try whether a sound wet rope is weaker than when dry.

3rd. To see if the loss of weight in old rope would be a guide as to the loss of strength.

4th. To test the stretching of ropes.

The results obtained with the lever beam are stated in Table IV.; while those observed in H.M. Dockyard, are recorded in Table V.

The following appear to be the general results :—

That a bend and seizing injures a rope less than almost any other fastening.

That (experiments 2 and 4) a clove hitch weakens a rope more than an eye-splice.

That with dry rope (experiments 10 and 11) a reef knot is as strong as the rope. With a wet rope, a reef knot slips (experiment 27), when a double sheet bend holds.

That a timber hitch seems to strain a rope about as much as a clove hitch: it always holds.

That (experiment 9) a gasket stopper may be $\frac{3}{5}$ths weaker than the rope it is made of.

In experiment 13, a 7-in. transom was lashed in the ordinary way to a 10-in. standard, with three complete turns and two frapping turns of $1\frac{1}{2}$-in. tarred rope; the strength of 12 ropes was therefore called into play. As it was inconvenient to measure the load the transom would support with the standard vertical, a force was applied to draw the transom up parallel to the standard when vertical. The amount of this was 15720 lbs. per lashing, or 1310 lbs. per rope, under which load the lashing parted, after yielding till the transom had risen $9\frac{1}{2}$ in. along the standard.

Similar experiments (17 to 19) with a transom and standard of 5 in. and 6 in., respectively, and with 1 in. tarred rope, give a mean result of 650 lbs. per rope.

From experiments 10 and 11, the 1-in. rope used for all these experiments was found to have a breaking weight of 685 lbs., while from experiments 14 to 16, the $1\frac{1}{2}$ in. has a breaking weight of 1270 lbs. From these it would appear that the full strength of the rope is to be relied on in the transom lashing; as, however, the breaking weight of $1\frac{1}{2}$-in. rope should be as high as 15 cwt. (or 1680 lbs.) it will be safer to assume that the ultimate holding power of each rope in the transom lashing to resist a force acting parallel to the standard, is at least $\frac{4}{5}$ths that of its breaking weight. Thus with a 2-in. lashing, having a breaking weight of $1\frac{1}{3}$ tons, used with four turns, the ultimate holding power would be $16 \times \frac{4}{5} \times \frac{4}{3} = 17{\cdot}2$ tons.

In experiment 12, a Spanish windlass was tested. It consisted of six ropes (1-in.), and had one turn per foot of length. As compared with the two previous experiments, the ropes appeared to have been weakened by the twisting to the amount of $\frac{1}{8}$th.

With regard to the splices, the eye and short splices appear to be nearly, though not quite, as strong as a bend and seizing, or as a half-hitch and seizing.

The long splices (experiments 20 to 22) gave results from 5 per cent. to 40 per cent. less than the probable ultimate strength of the ropes used.

Strength of wet ropes.

2. Experiments 23 and 24, on wet 3 in. and 2 in. ropes, shew lower results than with the same ropes when broken dry. While from experiments 25, 14, and 17, the 1½-in. and 1-in. ropes gave higher results when wet. On the whole, some diminution should, I think, be allowed for with sound wet ropes.

Stretching of ropes.

3. The most important results from Table V. are, that for large new hemp hawsers, such as are fit for suspension bridges, the amount of stretching is approximately $\frac{1}{23}$th, $\frac{1}{12}$th, $\frac{1}{11}$th, and $\frac{1}{9}$th, under loads of $\frac{1}{8}$th, $\frac{1}{4}$th, $\frac{1}{3}$rd, and $\frac{1}{2}$ the breaking weight.

Smaller ropes stretch only from $\frac{1}{3}$rd to $\frac{2}{3}$rds as much under similar loads. Coirhair or cocoa-nut fibre ropes stretch three or four times as much as hemp rope.

Strength of old ropes.

4. Experiments 28 to 33 failed to establish any relation between the loss of weight and the breaking weight of old ropes.

Experiments on the Cross-breaking Resistance of Green Timber.

Seven experiments on larch and oak are given in Table VI., where it appears that the strength of green larch to resist cross-breaking was to that of dry, as 8321 to 8900, or about $\frac{1}{15}$th weaker. While with oak, (though small and not matured), the strength of the green wood was only as 7783 to 10,000, or ¼ weaker than dry oak.

In green wood, the lower fibres appear to tear first; while with dry, failure almost always takes place by the crushing of the upper fibres.

Experiment 3 shews that failure occurs at the centre, even with a considerable taper towards the tip.

Appendix.

In Table I., under the head of "Dimensions of log used," round logs are indicated by the letter "R.," and half-round by "H.R."

In Table III the results marked * have been calculated from the experimental results.

In Table IV., the letters "W.," "T.," and "O.T.," stand for white, tarred, and old tarred ropes.

TABLE I

No. of Experiment.	Direction of pull.	Dimensions of anchor used.	Mean depth of face of anchor-log below surface.	Nature of soil.	Weight per cubic foot.	Angle of repose.	Condition of soil.	How anchor failed.	Ultimate resistance in lbs. per sqre. foot of surface.	Mean do. lbs.	REMARKS.
1		13 in. × 13 in. × 6 ft.	2 ft. 0 in.				Dry.	Slowly.	Over 900	......	The rammed earth only drew out of the hole.
2		Ditto	2 ft. 0 in.				Wet.	Do.	Under 900	......	Ditto.
3		9 in. × 9 in. × 4 ft.	1 ft. 0 in.				Dry.	Do.	1166·6	......	Ditto.
4		Ditto	2 ft. 0 in.	Loam	82lbs.	$\frac{2}{3}$	Do.	Suddenly.	1700	......	Ditto.
5		12 in. × 6 in. × 3 ft. H.R.	3 ft. 0 in.				Do.	V. Slowly.	3024	......	Ditto.
6		Ditto	2 ft. 0 in.				Do.	Slowly.	2150	......	Ditto.
7		Ditto	4 ft. 0 in.				Do.	Do.	5470	......	The surface disturbance extended to 4 ft. all round centre of log.
8		Ditto	1 ft. 0 in.				Do.	Do.	450	......	
9	vertical	10 in. × 3 ft. 6 in. R.	3 ft. 0 in.				Do.	Do.	3000	......	Surface disturbed for a radius of 3 ft. 6 in. round centre of log.
10		9 in. × 9 in. × 4 ft.	1 ft. 0 in.				Damp.	Do.	680	......	Only the rammed gravel drew out, the first 9 ins. were turf, &c.
11		Ditto	2 ft. 0 in.				Do.	Suddenly.	1430	......	Surface disturbed for 6 ft. by 3 ft. 9 in.
12		Ditto	3 ft. 0 in.	Gravel	118lbs.	$\frac{4}{5}$	Do.	Slowly.	3300	......	Ditto ditto for 6 ft. 6 in. by 4 ft.
13		Ditto	4 ft. 0 in.				Do.	Do.	4550	......	Ditto ditto for 7 ft. 3 in. by 5 ft.
14		9 in. × 4 ft. R.	2 ft. 4·5 in.				Do.	Do.	1190	......	Failed at once with 1,800 lbs. per sqr. foot of diametral surface.
15		Ditto	3 ft. 0 in.				Do.	V. Slowly.	2418	......	Or with 1,765 lbs. per ft. run. The anchor (a 9 in. fascine) bent, but did not cut.
16		9 in. × 9 in. × 4 ft.	2 ft. 0 in.	Sand	114lbs.	$\frac{2}{3}$	Do.	Suddenly.	942	......	The sand was not rammed, but had been poured into a large pit.
17		Ditto	3 ft. 0 in.				Do.	Slowly.	1587	......	
18	$\frac{1}{2}$	Ditto	1 ft. 6 in.	Loam	82lbs.	$\frac{2}{3}$	Wet.	Do.	2350	......	The earth bulged up over position of log.

TABLE I.—*continued.*

No. of Experiment.	Direction of pull.	Dimensions of anchor used.	Mean depth of face of anchor-log below surface.	Nature of soil.	Weight per cubic foot.	Angle of repose.	Condition of soil.	How anchor failed.	Ultimate resistance in lbs. per sqre. foot of surface.	Mean do. lbs.	REMARKS.
19	$\frac{1}{3}$	9 in. × 9 in. × 4 ft.	3 ft. 0 in.				Wet	Slowly.	4494	......	The earth bulged up over position of log.
20	$\frac{1}{1}$	6 in. × 12 in. × 3 ft. H.R.	2 ft. 0 in.					Do.	2632		From 20 and 23 the resistance per square foot of the small surface is $\frac{1}{4\cdot7}$ times greater than with the larger one.
21	$\frac{1}{1}$	6 in. × 12 in. × 1 ft. H.R.	2 ft. 0 in.					Do.	3516	2942	
22	$\frac{1}{1}$	6 in. × 12 in. × 3 ft. H.R.	2 ft. 0 in.					Do.	2822		
23	$\frac{1}{1}$	6 in. × 12 in. × 3 ft. H.R.	2 ft. 0 in.					Do.	2755		
24	$\frac{1}{3}$	6 in. by 12 in. × 3 ft. H.R.	2 ft. 0 in.					Do.	4032	......	1·48 times resistance at 45 deg.
25	$\frac{1}{2}$	6 in. × 12 in. × 3 ft. H.R.	2 ft. 0 in.					Do.	3882	......	1·44 times ditto ditto
26	$\frac{1}{4}$	6 in. × 12 in. × 3 ft. H.R.	2 ft. 0 in.						4368	......	1·62 times ditto ditto
27	$\frac{1}{1}$	6 in. × 12 in. × 3 ft. H.R.	1 ft. 0 in.	Loam.	82 lbs.	$\frac{2}{3}$	Dry	Quickly.	933	......	
28	$\frac{1}{1}$	6 in. × 12 in. × 3 ft. H.R.	3 ft. 0 in.					Slowly.	4400	......	
29	$\frac{1}{1}$	6 in. × 12 in. × 1·5 ft. H.R.	4 ft. 0 in.					V. Slowly.	9400	8000	As the length was short.
30	$\frac{1}{1}$	6 in. × 12 in. × 1 ft. H.R.	5 ft. 0 in.					Do.	27552	28000	Assuming that these surfaces gave too high a reading, as compared with 3 ft. logs by $\frac{1}{4\cdot7}$, the corrected reading would be, say 22,000 lbs.
31	$\frac{1}{1}$	6 in. × 12 in. × 8 in. H.R.	5 ft. 0 in.					Do.	28560		
32	$\frac{1}{2\cdot5}$	6 in. × 12 in. × 1 ft. H.R.	2 ft. 0 in.					Do.	7837	......	
33	vertical	6 in. × 12 in. × 1 ft. H.R.	5 ft. 0 in.					Do.	14112	......	
34	1	6 in. × 12 in. × 3 ft. H.R.	2·375 ft. 0 in.					Do.	3660	......	
35	vertical	6 in. × 12 in. × 2 ft. H.R.	2 ft. 0 in.	River clay.	83 lbs.	$\frac{1}{4}$	Wet	Quickly.	952	1148	Results just half those in loam. The clay was Medway mud below sub-soil water lev
36	$\frac{1}{1}$	6 in. × 12 in. × 2 ft. H.R.	2 ft. 0 in.					Do.	1344	......	

TABLE II.

Nature of Soil.	Tangent of Angle of Repose.	Weight of a Cubic Foot. lbs.	Relative Holding Power.
Compact loam, rammed (dry)	$\frac{2}{3}$	82	1·0
Hard compact gravel, rammed (dry)	$\frac{4}{5}$	118	·9
River clay (below subsoil water level), rammed (wet)	$\frac{1}{4}$	83	·5
Loose incoherent river sand, not rammed (damp)	$\frac{2}{3}$	114	·5

TABLE III.

Mean Depth of Face of Anchorage below Surface.	Direction of Force drawing Anchorage (perpendicular to its Face), and corresponding ultimate resistance in lbs. per square foot of anchor face.				
	Vertical.	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$
1 foot............................	808	933	1,244*	1,300*	1,430*
1 foot 6 inches................	1,040*	1,458*	2,100	2,180*	2,360*
2 feet	1,925	2,700	3,880	4,032	4,370
3 „	3,024	4,400	5,860*	6,160*	6,750*
4 „	5,470	8,000	10,660*	11,200*	12,260
5 „	14,112	22,000	29,330*	30,800*	33,730*
Mean variation of resistance according to direction of force	1	1·5	2	2·1	2·3

TABLE IV.

No. of Experiment.	Circumference of rope. ins.	Weight per fathom. lbs.	How secured. Above.	How secured. Below.	Whether spliced or knotted.	Clear length. ins.	Breaking weight of one rope. lbs.	REMARKS.
1	2 W.	0·6	Clove hitch.	Clove hitch.	No.	37	2062	New white manilla rope, circumference reduced to $1\frac{1}{2}$ ins. at breaking.
2	2 T.	0·86	Do.	Do.	No.	30	3270	New rope, circumference reduced to $1\frac{5}{8}$ in. at breaking.
3	3 T.	2·02	Eye splice.	Bend & seizing.	No.	..	7680	Broke just below eye splice, circumference reduced to $2\frac{3}{4}$ ins. at breaking.
4	2 T.	0·86	Do.	Do.	No.	..	4040	
5	3 T.M.	1·77	Clove.	Clove.	No.	..	7530	New manilla pontoon cable.
6	3 T.	2·02	Half hitches & seizings.		Short splice.	..	9540	Broke just above splice.
7	2 W.	0·6	Eye splice.	Eye.	No.	15	1680	Rope dry.
8	2 W.	0·6	Do.	Do.	No.	15	2405	Rope had been soaked for 72 hours in water.
9	3 T.	2·02	Eye splice.	Stopper hitch.	No.	..	4440	This was a gasket used as a stopper on a $3\frac{1}{2}$ in. rope, it broke in the half hitch of the stopper.
10	1 T.	0·3	Nil.	Nil.		34·6	683	Broke clear of reef-knot in each case.
11	1 T.	0·3	Nil.	Nil.	Reef knots.	40	687	
12	1 T.	0·3	Nil.	Nil.		36·5	595	This was a small Spanish windlass, with three complete turns.
13	$1\frac{1}{2}$ T.	0·565	Clove.	Clove.	No.	...	1310	Transom lashing; three complete turns used.
14	$1\frac{1}{2}$ T.	0·565	Nil.	Nil.		18	1067	
15	$1\frac{1}{2}$ T.	0·565	Nil.	Nil.	Reef knots.	34·5	1255	Mean B.W. = 1270 lbs.
16	$1\frac{1}{2}$ T.	0·565	Nil.	Nil.		35	1486	
17	1 T.	0·3	Clove.	Nil.	No.	..	550	
18	1 T.	0·3	Do.	Nil.	No.	..	700	These were transom lashings, each with three complete turns. Mean holding power for each part of a rope = 650 lbs.
19	1 T.	0·3	Do.	Nil.	No.	..	700	
20	3 T.	2·02				..	....	
21	2 T.	0·86	Timber hitches.	Turns and hitches.	Long splices.	..	....	Broke about middle of long splice in all three experiments.
22	$1\frac{1}{2}$ T.	0·56				..	....	
23	3 T.	2·02			No.	..	5376	
24	2 T.	0·86	Eye splices.	Clove hitches.	No.	..	2548	These three sets of rope had been previously soaked for 72 hours in water, and all broke just above the clove-hitches.
25	$1\frac{1}{2}$ T.	0·56			No.	..	1722	
26	$1\frac{1}{2}$ T.	0·56	Do.	Do.	No.	..	1610	Rope dry, broke as with the three preceding ropes.
27	1 T.	0·3	....	....	No.	..	952	Soaked for 72 hours. When secured with a reef knot, the reef knot slipped; but a double-sheet-bend held.
28	2 O.T.	0·75	Turns and seizings.		No.	18	2190	Broke just below upper seizing.
29	2 O.T.	0·86	Eye splice.	Eye splice.	No.	27·5	1695	
30	2 O.T.	0·86	Do.	Do.	No.	27·5	2465	
31	$2\frac{1}{2}$ O.T.	1·35	Do.	Do.	No.	27·5	3466	
32	2 O.T.	0·86	Do.	Do.	No.	17	690	Elongation $\frac{1}{34}$th at breaking.
33	3 O.T.	1·75	Do.	Do.	No.	16	2085	Elongation $\frac{1}{16}$th at breaking.

TABLE V.

Fraction of the Breaking load used.	Amount of elongation of different sizes of hawsers under various loads.												REMARKS.
	Hemp Hawsers.							Iron wire Hawsers.			Coir hair Hawsers.		
	$1\frac{1}{2}$ in.	2 in.	$2\frac{1}{2}$ in.	$4\frac{1}{2}$ in.	$6\frac{1}{2}$ in.	8 in.	9 in.	$2\frac{1}{2}$ in.	3 in.	$3\frac{1}{2}$ in.	3 in.	$3\frac{1}{2}$ in.	
$\frac{1}{8}$ B. W.......	..	...	...	...	..	$\frac{1}{32}$	$\frac{1}{21}$	$\frac{1}{576}$	..	$\frac{1}{576}$	..	...	All the hemp ropes were tarred except the $6\frac{1}{2}$in.
$\frac{1}{4}$ B. W.......	$\frac{1}{36}$	$\frac{1}{24}$	$\frac{1}{48}$	$\frac{1}{58}$	$\frac{1}{18}$	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{288}$	$\frac{1}{288}$	$\frac{1}{230}$	..	$\frac{1}{13}$	When the proof strain was taken off the 3in. wire rope, the permanent stretch was observed to be $2\frac{5}{8}$ ins.
$\frac{1}{3}$ B. W.......	$\frac{1}{18}$	$\frac{1}{17}$	$\frac{1}{28}$	$\frac{1}{36}$	$\frac{1}{14}$	$\frac{1}{11}$	$\frac{1}{11}$	...	...	..	..	$\frac{1}{11}$	
$\frac{1}{2}$ B. W.......	$\frac{1}{14}$	$\frac{1}{14}$	$\frac{1}{20}$	$\frac{1}{29}$	$\frac{1}{12}$	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{96}$	$\frac{1}{144}$	$\frac{1}{160}$	$\frac{1}{10}$	$\frac{1}{6}$	
$\frac{3}{4}$ B.W.(proof)	..	...	..	...	..	...	...	$\frac{1}{35}$	$\frac{1}{22}$	$\frac{1}{44}$	..	..	
B. W..	$\frac{1}{10}$	$\frac{1}{10}$	$\frac{1}{12}$	$\frac{1}{16}$	...	$\frac{1}{8}$	$\frac{1}{7}$	...	..	..	$\frac{1}{3}$	$\frac{2}{5}$	
Value of B. W. for each rope in tons.	$\frac{15}{20}$	$1\frac{9}{20}$ R.	2	$7\frac{3}{20}$ P.	15 I.	20 R.	$26\frac{15}{20}$ R.	6	$9\frac{19}{20}$	$12\frac{1}{2}$	$\frac{17}{20}$	$1\frac{6}{20}$	The letters R, P, and I, stand for Riga, Petersburg, & Italian hemp.

TABLE VI.

No. of Experiment.	Nature of wood.	Length of span, feet.	Diameter at centre, ins.	Central load, lbs.	Deflection at centre, ins.	Calculated value of f_0	REMARKS.
i.	Larch (green)	13	4	0 839 1287 1443	2 4·5 7 9	8321	The expression in which f_0 is used is $\frac{w\,l}{4} = f_0 \frac{\pi r^3}{4}$ (Rankine Civil Eng.)
ii.	Larch (green)	13	4·7	0 1299 1859 2195	3 6 9·5 15		The load was slung by spun-yarns from the centre of the spars ; the ends were only supported The breaking weight is the highest weight for each experiment in column 5.
iii.	Larch (green)	16	5·57	2629	..		Top fibres failed ; butt 8 in. in diameter. Tip only 3 in. in diameter.
iv.	Larch (dry)	13	3·7	0 839 1091	2·75 8 10	8900	Bottom fibres failed.
v.	Oak (green)	10	3	0 447 629	1·5 7·75 24	7783	Bottom fibres failed. For seasoned oak, $f_0 = 10{,}000$. (Rankine.)
vi.	Oak (green)	9	3·66	1375	9·75		
vii.	Oak (green)	10	3·26	0 174 209	2·5 10·5		

PAPER IX.

THE RECENT HISTORY OF EXPLOSIVE AGENTS.

By F. A. ABEL, F.R.S., Treas. C.S., &c.

Numerous as have been the attempts during the last sixteen years to apply other explosive agents as substitutes for gunpowder in small-arms and even in artillery, no rival of the latter has yet thoroughly established any good claims to success as a propelling agent, except for sporting purposes. Nor does it appear probable, considering the difficulties which have to be encountered in sufficiently regulating the explosive action of gunpowder to adapt it to the heavy artillery of the present day, that even the apparently most controllable of other explosive bodies—guncotton—will ultimately prove susceptible of safe application in any larger artillery than field guns. The ultimate failure of the repeated attempts made in Austria to apply guncotton to artillery and small-arms must not, however, be accepted as proof that no results of value are likely to be attained in this direction. A very decided advance had been made towards the successful employment of guncotton in field-guns before the Government Committee on Guncotton ceased to exist in 1868; and if the experiments on this subject, which were then suspended, as well as those relating to the employment of guncotton in military small-arms, have not been resumed, it is only because the Committee on Explosives, to whom the further investigation of these matters has been entrusted, has hitherto been fully occupied with the more immediately important investigations relating to gunpowder.

Attempts to apply substitutes for gunpowder in small-arms have in some instances been attended with partial success. Many of the substances tried have differed greatly from each other, but all of them have been more rapidly explosive and therefore more violent and destructive in their action than powder. Guncotton in one form or another has been repeatedly made the subject of patient experiment as a material for use in small-arms. The first attempts at its employment, made soon after its discovery in 1846, were disastrous in their results, and the success which long afterwards was believed to have been achieved by Von Lenk's indefatigable labours, in the production of a safe and uniform cartridge, ingeniously constructed of layers of braided guncotton threads, was not confirmed by experience. Several methods of reducing the rapidity and increasing the uniformity of action of guncotton in small-arms have since been made the subject of experiment in England. Some of these, which consisted in the uniform dilution of guncotton either with ordinary cotton or with less explosive varieties of the material, have furnished fairly efficient cartridges for sporting purposes, which, though wanting much in uniformity, have established for themselves a superiority over gunpowder in regard to freedom from smoke and fouling, and one or two other qualities. But the only direction in which substantial prospect of success has hitherto attended the use of guncotton cartridges in arms of precision, has been the conversion of guncotton pulp by moderate compression into very uniform masses, the rapidity and violence of explosion of which were retarded by impregnating them throughout with some perfectly inert material, thus enveloping each particle of guncotton in a film of non-explosive substance. The experiments upon this system of preparing cartridges have not been pursued for the last four years, but some very good targets at 500 yards were made with the service Enfield and Snider arms in 1867 and 1868, with cartridges of guncotton pulp impregnated with small quantities of paraffin or stearine. India-rubber has also been employed in a similar manner as a retarding and, at the same time, water-repelling agent. Considerable success has attended repeated trials on a small scale with a species of gunpowder devised by Mr. Punshon, in which the principle of dilution of guncotton is carried very far, the explosive being incorporated with large proportions of sugar and saltpetre. A preparation of somewhat similar nature, containing as one component an imperfect kind of guncotton made from sawdust, and known as Schultze's powder, has also acquired some reputation for sporting purposes, though scarcely bidding fair to compete in uniformity of action with the excellent gunpowder now manufactured for breech-loading rifles.

The application of powerful explosive agents in shells would appear at first sight to present little difficulty beyond that involved in the selection of a material which presents a decided advantage in point of disruptive power over gunpowder, without exerting an excessive disintegrating action upon the mass of the shell, and thereby effecting its comparatively harmless dispersion. An important obstacle to the employment of many of the more powerful explosive agents as charges for shells exists in their liability to premature explosion by the concussion which the shell has to sustain upon the discharge of the gun. Attempts to employ guncotton in shells have several times been attended by such premature explosions, more or less disastrous to the guns used. A few experiments were made by the late Committee on Guncotton upon the employment of that substance in this direction; spherical shells were safely fired from a mortar of 13 inches calibre, but disastrous results were obtained when this material was used as the charge of lead-coated or studded elongated projectiles, fired from rifled guns. A few were safely fired, but without any apparent alterations of conditions, others burst in the gun, and instead of simply indenting and scoring the bore, as would have been the case if a shell charged with powder had burst prematurely, one gun was rendered perfectly unserviceable by the violence of the explosion, and another was burst, the fragments being projected many hundred yards. Further systematic experiments have been continued for Government from time to time, with the view of discovering a safe and powerful explosive agent for shells. The relative disintegrating and scattering powers of a large number of explosive agents have been determined, in the first instance, by filling cast-iron shells of a particular calibre with the different materials; bursting these in a chamber of great strength, lined with wood; carefully collecting all fragments which could afterwards be found on the floor, and which could readily be extracted from the walls of the chambers, and determining the individual and total weights of these. In this way the extent to which the different shells were broken up by the explosion was correctly ascertained, and many explosive agents—for which great power had been claimed, but which proved to be not greatly superior to gunpowder—were eliminated, the most powerful being selected for further experiment. In illustration of the results thus arrived at, it may be stated that, when a shell weighing 16 lb. 1 oz., filled with powder, was burst, all the fragments were readily recovered; they amounted to eighteen, including the plug of the shell, and of these, twelve weighed above 8 oz. and under 2 lbs., and only one fragment weighed less than 1 oz. Upon bursting a shell of the same kind and weight, filled with a mixture of potassium-chlorate and potassium-picrate, 100 fragments were recovered, and these weighed altogether only 2 lb. 6 oz., nearly 14 lb. of the shell having been dispersed in fragments too minute to be collected individually. Only one of the recovered fragments weighed more than 8 oz., and ninety-three weighed less than 1 oz.. It need scarcely be stated that such a disintegration of the shell would be far too considerable to render the latter of value as a destructive missile, but the result showed that a small proportion in weight of this potassium-picrate powder, if it could be used in shells, would suffice to produce the desired breaking up of the shell and violent scattering of the fragments, and that therefore the thickness of metal of the shell, and its consequent destructive power, might be very considerably increased. The chilled iron or Palliser shells, which, being of considerable thickness, hold comparatively small charges of powder, would obviously be rendered much more destructive as shells, by substituting for the powder charges an explosive agent even considerably less violent in its action than the one just cited as an example.

The shell experiments above referred to were followed by a series of another kind, instituted in the first instance for the purpose of determining the relative susceptibility to explosion, by concussion or other mechanical causes, of gunpowder, and of the explosive agents selected from the results of previous experiments as most promising in their nature. These experiments consisted in interposing definite quantities of the materials between flat brass plates, placing them upon a rigid support, and allowing a weight to fall upon them from different heights.

The conditions, which are variable in such experiments, require, however, very careful regulation, as the results attained may be modified to almost any extent by variations of such elements as the area of the surface of material struck, the thickness of the mass, its mechanical condition (whether in coarse or fine powder, or in a rigid or plastic mass), the nature of the materials composing the weight, and the anvil or support. Thus, a layer of mealed powder 0·05 in. thick, placed between two flat brass plates 1 in. square, is exploded by the blow of a 50 lb. weight falling from a minimum height of 36 feet, while a layer of the same thickness placed between brass plates like the preceding, but 0·5 in. square, is exploded by a fall of the 50 lb. weight from a height of about 9 feet. Small flat charges of fine-grain powder weighing five grains, enclosed in tinfoil and placed upon a steel support, were always exploded, in ten successive experiments, by the fall of a steel 25-lb. weight from a height of 2 feet; when a brass support was substituted for that of steel, only four charges out of ten were exploded; when both weight and support were of brass, only two out of ten were fired; and when the support and weight were of lead or wood, no explosion was obtained, even when the weight fell from a height of 40 feet. Again, a nitro-glycerine preparation, of which a layer of a particular thickness, placed between brass plates resting on a solid block of iron, was exploded by a fall of a 50-lb. weight from a height of 2 feet, was not exploded by a fall of 40 feet, when the lower brass plate was fixed upon a wooden block, the upper plate being attached to the weight by means of a small block of wood.

Of the many explosive preparations more violent than gunpowder which have been submitted to comparative experiments of the above nature, a mixture of ammonium-picrate with saltpetre proved the least sensitive to explosion by blow, thus contrasting remarkably with the violently explosive mixtures of potassium-picrate, which have been made the subject of experiment in France.

Picric acid, or carbazotic acid, as it was first called, is one of the earliest explosive substances of organic origin known, having been discovered as far back as 1788. It is produced by the action of nitric acid on a variety of organic substances. One of the earlier methods of obtaining it readily was by the action of nitric acid on indigo; but a comparatively abundant source of it was pointed out about thirteen years ago by Stenhouse, who readily produced it in large quantities by acting with nitric acid upon the resin of "Xanthorrhœa saxtilis," which was imported in considerable quantities from Botany Bay. Since the manufacture of phenol or carbolic acid from coal tar has become developed, picric acid has been very extensively produced from that substance, and, as a cheap and brilliant yellow dye, has become an important article of commerce.

The acid itself does not explode, but burns quickly with a bright flame; its salts are all more or less powerfully explosive, and detonate when struck. The potassium salt is that most easily prepared, on account of its very slight solubility in water. It is also one of the most highly explosive. When mixed with oxidising agents, and especially with chlorate of potash, it furnishes very powerful explosive materials; indeed, the chlorate mixture approaches nitro-glycerine and guncotton more nearly in violence of action than any other explosive agent produceable on a practical scale. This mixture is, however, so susceptible of detonation by friction or percussion, as not merely to render its employment in shells impossible, but also to preclude its application to any purpose without the adoption of very special precautions. Other mixtures containing potassium-picrate have been made the subject of experiment, especially in Paris, where so-called "*poudre picrate*," or *poudre Designolle*, composed of potassium-chlorate, potassium-picrate, charcoal, and saltpetre, was prepared and experimented with upon a considerable scale about three years ago, as a substitute for gunpowder in firearms, and for other purposes. A fearful accident at a factory in Paris, where large quantities of the potassium-picrate were manufactured, led to the abandonment of these experiments; but there appears little doubt that picrate preparations were included among the agents of destruction employed by the Communists in the recent struggle at Paris. In the course of the experiments with shells containing various explosive substances, to which reference has just now been made, the author was led to examine the properties of mixtures of ammonium-picrate with oxidising agents. This picric compound, which may be readily prepared upon a large scale, differs importantly in its behaviour, when exposed to heat, from the potassium-picrate, and from several other salts of this acid. When heated over a flame it fuses, sublimes, and burns without any tendency to explosion, while the potassium salt detonates under the same conditions. The latter also detonates somewhat violently when submitted to a moderate blow, whilst it is difficult to obtain evidence of detonation of the ammonium salt when struck sharply and repeatedly. A mixture of the potassium salt with saltpetre, though less susceptible to explosion by a slight blow than the chlorate mixture, is yet powerfully detonating; while a mixture of ammonium-picrate and saltpetre requires a violent blow to develop slight and partial detonation, and exhibits no tendency to ignition when submitted to very severe friction, which would at once explode the least sensitive of the explosive mixtures proposed as substitutes for powder. When flame is applied to particles of the mixture of saltpetre and the ammonium salt (to which the author has given the distinctive name "picric powder"), the individual particles deflagrate with a hissing sound like that of the sudden escape of steam, and the deflagration has little or no tendency to spread to contiguous particles; but if the mixture is strongly confined, as in shells, it explodes violently, and exerts a destructive action, less formidable than that of guncotton, nitro-glycerine preparations, and potassium-picrate powder, but considerably greater than that of gunpowder; it is therefore likely to prove a valuable substitute for the latter when greater violence of action is desired with shells of small capacity. A number of shells charged with picric powder have been fired without a single casualty from guns of different calibres, ranging to the 9-inch gun, with the employment of a battering charge of 43 lb. of R.L.G. powder. The safety of this substance is therefore considered sufficiently established to warrant the institution of thorough trials of its powers as an explosive agent for shells. It is a curious and important circumstance connected with this mixture, that though ammonium-picrate and potassium-nitrate undergo mutual decomposition, with production of the deliquescent ammonium-nitrate, if the two be *dissolved* together in water, the addition of sufficient water even thoroughly to moisten the mixture appears to induce no such change, as the latter, when dried again, has no increased tendency to absorb moisture from the air, which it scarcely does to the same extent as gunpowder. The picric powder is therefore quite equal in permanence to gunpowder, and as water may be used in incorporating the ingredients without any detriment to the stability of the mixture, its preparation is, at any rate, not more dangerous than the manufacture of gunpowder, and it may be safely submitted to the pressing and granulating processes which are applied to the latter. As, moreover, the cost of picric powder, as compared to its power, is not considerable, this explosive agent is now recognized as susceptible of advantageous application to service purposes, provided its sufficient superiority over powder in regard to violence of action is satisfactorily established.

Some comparative experiments have been instituted with picric powder and dry compressed guncotton in submarine mines, the results of which indicated that the two were not very widely different from each other in regard to their destructive action, when applied under the pressure of water most advantageous to the development of their explosive force. Although *wet* compressed guncotton is decidedly the most efficient agent of the two for use in submarine mines, the granular form of picric powder renders the latter susceptible of employment with decided advantage in small offensive torpedoes (such as the outrigger—or the Harvey torpedo), as they can be more conveniently and thoroughly filled with the granular explosive material than if the ordinarily available discs or slabs of compressed guncotton are employed.

Most important progress has been made during the last few years, in the application of explosive agents, more violent than powder, to mining and quarrying, and to various civil and military engineering purposes.

The successful employment of tunnelling machines within the last few years has demonstrated, more forcibly than could otherwise have been done, the great advantage in saving of time which must accrue from the employment of a more powerful blasting material than common gunpowder. But even in many ordinary blasting operations, there is no difficulty in showing that an important saving of time and labour may be effected in many kinds of work by employing a more powerful explosive agent than blasting powder; the possibility of using blast holes of reduced dimensions, and of increasing their distance from each other without detriment to the magnitude of the results, being advantages of the most obvious description. It appears to have been repeatedly demonstrated by practical trials that, in the removal of hard rock, in tunnelling, and in other operations of this class, decided advantages are gained in point of rapidity of work, by the employment of gunpowder of higher quality than ordinary mining powder; but those advantages will not bear comparison with the results attainable by the employment of certain explosive agents of a decidedly more violent character. There are, however, some directions in which ordinary blasting powder does not appear to be replaceable with advantage, if at all, by the explosive agents which are formidable rivals to it in other directions.

Ever since chlorate of potash has been produced upon a manufacturing scale, attempts have been made from time to time to utilise its comparatively violent oxidising power in the production of explosive mixtures more powerful than gunpowder, and applicable to its various uses.

Preparations consisting of chlorate of potash mixed with certain sulphides, with the prussiates of potash, with sugar or starch—these substances being either employed alone or in admixture with sulphur and other substances—have been brought forward at various times and under a variety of names as gunpowder-substitutes, the earliest of them being known as German gunpowder, and white gunpowder; but the property which they all possessed, of being exploded when submitted to comparatively moderate friction or percussion, was alone sufficient to prevent their being accepted as practically useful explosive agents, even if decided advantages could have been established for them by a proper comparison of their cost and efficiency with those of gunpowder. Ingenious attempts have been made to reduce the dangerous nature of chlorate of potash mixtures by impregnating or covering them with inert materials designed to serve as protective agents, by absorbing or deadening the violence of blows, friction, or concussion to which they might be subject; but, while such contrivances were only partially successful in guarding against liability to accident, they so considerably reduced the rapidity and violence of explosion of the materials to which they were applied as to preclude these from competing successfully with powder from an economical point of view.

A few comparatively safe preparations containing chlorate of potash have, however, been devised, some of which have furnished results in competition with powder, as mining and quarrying agents, so far favourable as to render it probable that they would have met with somewhat extensive application, but for the practical development of another class of explosive agents, which have within the last few years become formidable rivals of gunpowder. These chlorate-preparations are of several descriptions; one kind consists of mixtures of the salt with organic substances containing, in addition to carbon, a considerable proportion of hydrogen, such as powdered nut-galls, tannin, and resins. The preparation of powdered nut-galls and chlorate, known as Horsley's powder, which may be considered the type of these mixtures, has been found in practice to possess decided superiority over gunpowder in regard to violence of action, and to be much safer than any chlorate-preparation previously used. Another preparation, in which chlorate of potash was applied with comparative safety to blasting and other purposes, was first devised by Messrs. Hochstädter, in 1860, and subsequently reproduced with slight modification by M. Reichen. Strips of bibulous paper were soaked in a pasty mass consisting essentially of a mixture of chlorate of potash, saltpetre, charcoal, (and small quantities of other readily oxidisible substances) together with a little gum or other binding material dissolved in water. The paper became coated with the explosive mixture, and, at the same time, impregnated with the oxidising salts, of which it absorbed part of the solution; the strips were rolled up tightly while wet, and when dry furnished hard and compact cylindrical masses, which were violently explosive when confined, but resisted detonation to a very high degree when submitted to percussion or friction.

Some other comparatively safe applications have been made of chlorate of potash to the preparation of explosive agents for mining purposes, by only partly replacing saltpetre with it in mixtures either of similar composition to ordinary gunpowder, or containing sulphides besides free sulphur. A substance called Tutonite, for which special advantages as a blasting agent have recently been claimed, appears to belong to this class of preparations. It possesses the peculiarity of being made up in the form of somewhat hard pellets or discs, instead of being in the granulated or pulverulent form.

A few explosive agents have been applied as substitutes for gunpowder (and proposed in the first instance purely for industrial purposes) which present this peculiarity—that their claim to consideration has been based, not, or only in a minor degree, upon superiority in point of power, but upon special advantages in point of economy, safety in manufacture and use, and peculiar fitness for employment as blasting agents. One of these was specially a "safety-powder," devised by Messrs. Kellow, and manufactured near Plymouth a few years ago. It consisted of spent tan and sawdust, which were saturated with saltpetre or nitrate of soda and a little chlorate of potash, the product being afterwards very crudely mixed with sulphur. This preparation simply deflagrated with some difficulty when set fire to in open air; but when used with tamping, in the ordinary way, it appears to have competed very fairly with common blasting powder. Preparations of a nature almost identical with it have quite recently been brought before the public under the names of Pyrolythe and Pudlorythe. Another blasting agent of this class was invented in 1862 by a Belgian officer, Captain Wynants, and consisted of a mixture of charcoal and nitrate of baryta, either alone or with a proportion of saltpetre. The objects aimed at in producing this "poudre barytique," or "saxifragine," were, in addition to economy, the production of a powder which should act with gradually accumulating force, and which should only be applicable as a blasting powder, so that supplies placed in the hands of miners could not be diverted to other purposes. The first-named object was certainly attained, the baryta-powder being comparatively very slow-burning; and its special characters are such that its application could but remain limited to ordinary mining and quarrying uses, although its inventor did after a time propose that it should be applied, by admixture with ordinary cannon-powder, to moderate and regulate the pressure exerted by heavy charges in guns of large calibre; a result which has been attained with great success, and in a more philosophical and practically efficient manner, by simple modifications of the physical and mechanical condition of ordinary gunpowder.

Gun-cotton and nitroglycerine were discovered within two years of each other; but, while attempts were almost immediately made to apply gun-cotton to industrial purposes, its nature and the conditions essential to its successful development as a useful and reliable explosive agent being at the time very imperfectly understood, nitroglycerine was destined to remain a chemical curiosity for about sixteen years. It need scarcely be said that gun-cotton did not long maintain the advanced position into which it was forced at an early stage of its history. Disastrous accidents in England and in France, which occurred within three years of its discovery, completely destroyed the unbounded confidence too hastily placed in the mastery supposed to have been attained over its manufacture and properties; they led to its entire abandonment in England and in France for about sixteen years, and it was only in Germany that faith in its ultimate success was not altogether lost, thanks to the untiring perseverance of an Austrian artillery officer, Baron von Lenk. Yet the early applications of gun-cotton, especially in England, were not without importance; the well-known gunpowder makers, Messrs. Hall, of Faversham, entered energetically upon its manufacture within a year of its discovery; its important superiority over gunpowder in many mining and blasting operations was soon made manifest, and the demand for mining charges (consisting of gun-cotton wool tightly rammed into cardboard cases), was steadily increasing, when Messrs. Hall's works were destroyed by the explosion of 1847. Numerous specimens of gun-cotton, made soon after the announcement of Schönbein's discovery, have remained quite unchanged to this day; these and portions of the products of manufacture at Faversham, some of which, after having been buried since the time of the explosion, were recovered nine years ago, and are now in a perfect condition, demonstrate that even in those days stable gun-cotton was sometimes produced, and indicate that the accidents at Faversham and in France, which appear beyond doubt to have arisen from spontaneous ignition during manufacture or storage, were due rather to uncertainty in regard to the quality of the product obtained than to an inherent instability of the properly prepared material.

It was not until 1864 that gun-cotton again began to receive attention at the hands of practical men in this country, as an explosive agent susceptible of application to industrial purposes. Its manufacture had in the meantime been carefully studied and decidedly improved by Baron von Lenk, who had also devised a system (which has been described in a previous Paper in Vol. XV.) of applying gun-cotton which appeared to afford prospects of rendering it much more readily susceptible of adaptation to different purposes than the original gun-cotton wool of Schönbein. Von Lenk's mining charges consisted of pieces of suitable length of a compact gun-cotton twist or rope, kept hollow in the centre, for the double purpose of receiving the fuze and of causing the charge, when inflamed, to ignite throughout more readily than it would if quite solid, unless strongly confined. Gun-cotton in this form was made the subject of an extensive series of experiments by Baron von Ebner, of the Imperial Austrian Engineers, with the view of testing its applicability to the various military and civil mining and engineering operations to which gunpowder is applied. For blasting in hard rock, the operation being conducted just as with gunpowder, the force of gun-cotton was found to be so superior that, spite of its comparatively high price when made according to von Lenk's system, a decided saving in cost was effected. In comparatively soft rock the results, though less marked, were still advantageous, provided the rock was free from fissures; if these existed, in any kind of rock, the efficiency of the gun-cotton was more or less seriously interfered with, as its full explosive force was not developed unless the material was closely confined at the moment of explosion. For submarine operations, gun-cotton in the form of rope offered decided advantages over powder, provided it was confined in strong cases, and gun-cotton was consequently adopted as the explosive agent in the submarine mines which were applied by the Austrians in their last war to the defence of Venice, Pola, and Lissa. The absolute necessity for strong confinement of the material was, however, a serious obstacle to its ready and effective employment in open-air operations, such as the destruction of stockades, or the hasty demolition of bridges, buildings, or works; for although Baron von Ebner described some successful operations in his report, the gun-cotton having been confined in cases constructed of stout wood and sheet metal, the fact that even strong receptacles of this kind could not be relied upon to afford the initial resistance essential to the proper explosion of the gun-cotton, was demonstrated by repeated failures in the course of the demolition of works at Corfu by the Royal Engineers in 1863, when attempts were made to apply large charges of gun-cotton-rope, furnished for the purpose in specially constructed cases by the Austrian Government.

The explosion, in 1862, of a magazine near Vienna, where 28 cwt. of gun-cotton were stored with a quantity of gunpowder, and one of much greater magnitude in 1865, of neither of which any satisfactory explanation was afforded, led to the abandonment of gun-cotton in Austria; but, meanwhile, experience in the manufacture of the material according to von Lenk's system, and in its application to industrial and other purposes, was being acquired in this country.

In October, 1864, at which time gun-cotton manufactured by Messrs. Prentice, of Stowmarket, was already being used to an experimental extent in some mining districts in England, and the special committee appointed by Government, under the presidency of Sir Edward Sabine, to investigate the merits of gun-cotton made and used according to the Austrian system, instituted a series of comparative experiments with gunpowder and gun-cotton in the lead mines and quarries of Mr. W. B. Beaumont, M.P., near Allenheads.* In attempting to form some estimate of the relative power and efficiency of the two explosives, the committee became strongly impressed with the great difficulty of instituting really comparative blasting and quarrying operations. In rock which appears uniform and quite sound, the blasting often brings to light veins, shakes or fissures which render a comparison of work done in two contiguous portions impossible. Even in very homogeneous hard rock, differences in structure occur which modify the resistance opposed to the explosive agent, while it is almost impossible to have two blast-holes, for comparative experiments, so placed in actual practice that their position with reference to the exposed surfaces or faces of the rock, or, in other words, the direction of least resistance, should be more than approximately alike. The results obtained at Allenheads were in most instances favourable to gun-cotton, bulk for bulk, but they varied considerably

* Reports relative to the application of gun-cotton to mining and quarrying operations, printed for the House of Commons, April, 1869.

among themselves for the reasons given. One of the committee, Mr. Sopwith, M. Inst. C.E., believed that trustworthy data regarding the relative power of different explosive agents would be best obtained by performing blasting experiments in artificially prepared homogeneous masses as closely alike as could possibly be insured; he suggested blocks of carefully prepared concrete as a suitable material. A few experiments on a comparatively small scale, which the author executed with concrete blocks, indicated that more trustworthy results might thus be obtained than by comparing the results of ordinary blasting operations; but precise experiments in this direction have as yet been of a limited character.

One decided advantage which gun-cotton was found to possess as a blasting agent, in the experiments of the committee, and which was confirmed by practical experience in underground work, was the absence of smoke; the miners were enabled to return to their work in a much shorter time after a blast with gun-cotton than when powder was used; but this was not the case if the rock operated upon was unsound, or if the resistance opposed to the gun-cotton was insufficient to develope its full explosive force; the incomplete explosion of gun-cotton being attended by the development of vapours of an irritating character, which could not be inspired without much inconvenience. An important objection to the Austrian mining charges of gun-cotton-rope was the comparatively loose condition, or the want of rigidity, of the material, which caused it to be easily altered in shape (or upset) if any force were used in pushing a somewhat tightly-fitting charge down a hole; if an attempt was then made to drive home the charge it became tightly jammed, and several accidents occurred in consequence of the explosion of charges of gun-cotton-rope by the great friction to which portions were exposed in the violent treatment adopted by the miners in driving home a jammed charge.

Some advantage was derived with the gun-cotton-rope charges from an increase in the amount of tamping which could be introduced into holes of a given length, owing to the reduction in the length of charge required as compared with powder; but the gain in this direction was greatly increased when the Austrian form of charge was replaced by compressed gun-cotton, the manufacture of which was devised and elaborated by the author in 1868. The density of the former was about 30 lb. per cubic foot, while that of the latter was about 60 lb.; this, and the difference in the form of the charges, caused the compresed gun-cotton to occupy somewhat less than half the space of the rope charges; hence the blast-holes could be reduced in length and diameter, or a considerably larger amount of tamping could be used; or, if necessary, a larger charge of gun-cotton could be employed in any one operation. The smooth and hard exterior of the cylindrical charges of compressed gun-cotton rendered the operation of loading with them comparatively easy, and it was only in rugged and uneven holes that there was a liability of the charge to become jammed. Accidental ignitions and explosions have, however, occurred with compressed gun-cotton, in consequence of the great amount of violence used in forcing or driving home the charge. If it should happen to be ignited by powerful friction just as the force of a blow is spent and the jumper or driving-rod is being withdrawn, it will simply burn, but if the ignition takes place while the implement is pressing upon the charge, the full force of the operator being perhaps applied at the moment, the conditions are obviously the same as though the gun-cotton were firmly tamped, and a violent explosion must result. It is a question however, whether, if wooden tamping-rods had been used in the place of metal tools, the accidents which have occurred in charging holes with gun-cotton might not have been in great measure avoided.

In addition to the advantages which have been pointed out as resulting from the production of compressed gun-cotton, there are some others which have a direct bearing upon its application to industrial purposes. The employment of cotton waste in its production, in place of long staple cotton of high quality, which was required in the manufacture of the Austrian gun-cotton, and the important saving of time effected in the manufacture of mining charges, have led to a considerable cheapening of the material. The incorporation of at least ten hundredweight of gun-cotton at one time, in the purifying process which it undergoes after reduction to pulp, and before it is pressed into charges, gives rise to far greater uniformity than could possibly be attained, even with the most extreme care, when the products of separate small operations of manufacture were directly converted into charges. The circumstance that the compressed charges do not burn with the explosive violence exhibited by spun gun-cotton, even if they are confined in the packing cases ordinarily used, renders the material much safer to store and handle, and has reduced considerably the chances of explosions resulting from the accidental ignition of the material during transport and in store. An additional and important element of safety arises from the superior efficiency of the purifying treatment to which the gun-cotton is subjected in the finely-divided form, as compared with the old system of washing the long fibres of gun-cotton.

One of the chief advantages of compressed gun-cotton consists in the convenient and safe form in which the charges are furnished to the miners, who carry them about and handle them without fear or risk of accident; unfortunately, this advantage cannot but constitute occasionally an indirect source of danger, as an over confidence in the safety of the material will lead the miner to forget at times that he is dealing with an explosive agent, and hence he will occasionally perform reckless acts in charging the blast-holes, which must inevitably end in disaster.

A most important advantage which has resulted from the conversion of gun-cotton into homogeneous compressed masses will be dealt with more conveniently when the methods of applying the companion explosive agent, nitroglycerine, have been examined into.

Nitroglycerine has been raised from the position which, as already stated, it held for sixteen years as a rare and apparently useless chemical product, to that of a most important industrial agent, entirely through the skill, ingenuity, and perseverance of Mr. Alfred Nobel. While repeated efforts were made to utilise gun-cotton and to perfect its manufacture, nitroglycerine continued to be regarded by chemists as akin to the chloride of nitrogen with respect to its uncontrollably dangerous character and its instability, and as being utterly unsusceptible of practical application, partly on account of the difficulty of bringing about its explosion by practicable methods, and partly on account of the great danger supposed to attend its manufacture and all manipulations connected with it.

At about the time when the Austrian improvements in the application of gun-cotton began to receive attention in England, Mr. Nobel made public his first attempts to apply nitroglycerine to practical purposes. In 1863 he proposed to add to the explosive power of gunpowder used in the ordinary way by impregnating the grains with nitroglycerine. This proposal was speedily followed by Mr. Nobel's discovery of a satisfactory method of developing the explosive force of nitroglycerine, either in its pure state or in admixture with other substances. The fact that nitroglycerine and analogous bodies are only slowly burned or gradually decomposed when brought into contact with an ignited body in the open air, unlike gunpowder and other explosive mixtures, led Mr. Nobel to conclude that it was necessary, in order to determine their explosion, to raise them, or some portion of them, rapidly to the temperature at which that result would be produced, and that if only a small portion were thus heated to the exploding point the explosion of the entire mass would be brought about. In 1864 Mr. Nobel described several methods for raising portions of a charge of nitroglycerine to the temperature necessary for developing what he termed the initiative explosion; of these the really efficient one consisted in exploding a large percussion cap in contact with, or in close proximity to, the charge of nitroglycerine. It was found that the explosive metamorphosis proceeds with such almost instantaneous rapidity throughout the mass, from the portion in immediate proximity to the initiative agent, that confinement by tamping or other means is not required for the full development of the explosive force of nitroglycerine. The author was led, in 1867-8, to examine into the general question of the conditions which determine and regulate the explosion of compounds and mixtures, and did not find that Mr. Nobel's explanation of the development of detonation furnished a sufficiently satisfactory solution of many results obtained with nitroglycerine and other explosive agents. But there is no question that Mr. Nobel was the first to apply an initiative explosion or detonation to the ready development of explosive force from substances which otherwise will not readily operate explosively, and that he was also the first to succeed in applying a liquid explosive agent to practical purposes.

While a mode of applying nitroglycerine was thus being established by Mr. Nobel, he also developed the manufacture and purification of the material to so great an extent that the grave doubts entertained until within a recent period regarding the possibility of regularly producing it in a condition of purity and stability, which were fully warranted by the previous experience of chemists, have already given place to considerable confidence in the keeping properties of the substance.

Nitroglycerine in its pure or undiluted condition was soon demonstrated to be the most powerful explosive agent yet made known. The economy in time and labour effected by its use in blasting and tunnelling in hard rock is undoubtedly greater, under favourable circumstances, than with gun-cotton or any of the most powerful substitutes for gunpowder. Moreover, the liquid form, high specific gravity, and insolubility in water of nitroglycerine, are peculiarly valuable properties under some circumstances; thus, blasting in wet holes, or actually under water, can be carried on with nitroglycerine expeditiously and without any special appliances. The efficiency of nitroglycerine as a mining agent having been established in Sweden and in Germany, demands soon arose for the material in other countries, and it has been extensively employed in mining districts abroad, especially in California. In Wales it was used by some quarry-owners as a most efficient agent for tunnelling and for removing the hard rock overlying the slate; but the liquid nature of the material, and one or two of its other properties, were soon found to constitute important sources of inconvenience and danger.

The poisonous nature of nitroglycerine, which injuriously affects the health of those handling and using it, is one of its defects. It is stated, however, that the human system may become accustomed to its influence, so that after a time the prejudicial effects on health, or the inconvenience attending the employment of nitroglycerine and its preparations, diminish or subside altogether. At any rate, there is no doubt that miners would not be deterred by these defects from availing themselves of the advantages presented by a powerful and efficient blasting agent. The comparatively high temperature at which nitroglycerine freezes, and the slowness with which it thaws, even at normal atmospheric temperatures, constituted a source of inconvenience, and, in some respects, of danger, though not perhaps in the particular direction in which many who have devoted attention to these subjects at first believed. The facility and violence with which a solid explosive agent will undergo detonation, when exposed to the operation of mechanical force, are in inverse proportion to the readiness with which the particles of the mass can yield to, or be moved by, the blow applied; thus, a highly-compressed mass of a fulminate-mixture can be exploded by a much lighter blow than a portion of the same mixture in the state of powder, because, in the latter case, the force of the blow is partly expended in mechanical work upon the loose particles of the mass struck. Similarly, therefore, it was believed that the yielding or mobile condition of the particles of a liquid must render it less susceptible to explosion by a blow or violent concussion than the same material in a solid condition. This view appeared, in the instance of nitroglycerine, to be supported by some fearful accidents which occurred in Sweden and in this country during the handling of frozen nitroglycerine. It has, however, been established beyond all doubt, that the material is much less susceptible of detonation in the frozen than in the liquid condition; the comparative inertness of the frozen substance constituting in fact, occasionally, a source of considerable inconvenience. In considering the behaviour of the substance when subjected, in the different physical conditions, to heat suddenly applied through the agency of friction or a blow, the fact was overlooked that the transformation of the liquid into gas must involve much less expenditure of heat than the same transformation of the solid, or frozen body—a circumstance to which the inferior sensitiveness of the latter to detonation must be, at any rate, mainly ascribed. The accidents which occurred with frozen nitroglycerine appear to have arisen from a recklessly rough usage of the material; and, so far as the apparently great safety or inertness of the frozen substance will lead to occasional recklessness, it does constitute a source of danger. The necessity for thawing the nitroglycerine (and its preparations) for use, unless exploding arrangements of a special character be provided, has also proved to be a source of accident; for though simple and safe regulations for thawing have been laid down and prominently insisted upon, it is impossible to guard against occasional mistakes, or against the deliberate thoughtlessness which is, in the mining districts, so fruitful of casualties with gunpowder.

The principal defect of nitroglycerine, when employed in its pure state as a blasting material, arises, however, from its liquid nature, and its consequent tendency to leak out of receptacles in which it is transported, stored, or used. In blasting operations the nitroglycerine with which a hole is charged will flow into fissures in the rock, and may thus be conveyed to parts where its existence cannot be suspected, and where it may be afterwards accidentally exploded during the boring of other holes. Numerous more or less terrible nitroglycerine explosions have occurred in different parts of the world, the majority of which are considered to have been primarily due to the leakage of nitroglycerine from the packages in which it was transported and stored, notwithstanding the care with which these were constructed and packed. The great susceptibility of nitroglycerine in the liquid form to detonation, especially during hot weather or in tropical climates, would lead to the explosion of portions of the liquid which had escaped from the packages, by accidental concussion, or comparatively slight blows, and thus disastrous explosions would be brought about. In order to reduce the chances of accident, Mr. Nobel adopted the ingenious precaution of dissolving nitroglycerine in wood spirit, and diluting it with that solvent sufficiently to render the mixture quite non-explosive, the oil being easily separated, when required, by the simple addition of water. But this precautionary measure was only partially successful, because the vapour of the highly volatile wood spirit readily escaped from minute imperfections in the packages, and, as the spirit became weaker, an explosive mixture of nitroglycerine with a small proportion of spirit collected at the bottom of the vessel, the material thus being restored to a dangerous condition.

In the course of Mr. Nobel's persevering endeavours to counteract or reduce the sources of danger attending the use of nitroglycerine, he made the most important observation that the readiness or certainty with which it exploded through the agency of a detonation is not reduced, but on the contrary, somewhat favoured, by mixing the liquid with solid substances, in themselves thoroughly inert. This discovery led at once to the production by Nobel of solid, or more or less pasty, preparations of nitroglycerine, which, under the name of dynamite, were first brought before the public in 1867, and the most perfect of which constitutes, as now manufactured, one of the safest, most powerful, and most convenient explosive agents applicable to industrial purposes. By the absorption of nitroglycerine by porous solids, or its mixture with non-absorbent solid bodies in a fine state of division, that substance is presented in a condition in which it may be manipulated like any solid explosive substance, with the additional advantage of plasticity; and if such a preparation is made according to the system now pursued by Nobel, it appears to set aside completely, or nearly so, all objections to nitroglycerine which could arise out of its liquid form. It is true that by diluting nitroglycerine with non-explosive substances, or even with other less powerful explosive materials, the force available from a given weight of substance becomes diminished; but the power of pure nitroglycerine is so much greater than that of gunpowder, that it will bear considerable dilution without important detriment to the high position which it holds among powerful explosive agents.

The form in which dynamite was first presented to the public, was that of a loose, soft, readily mouldable powder of a pink or buff colour, which consisted of about 75 parts of nitroglycerine held absorbed by 25 parts of a porous, infusorial, siliceous earth, known in Germany as "kieselguhr." The moist appearance of this powder favoured the opinion that the nitroglycerine would be liable to exude from it, or concentrate itself at the base of a package during transport or long-continued storage. The dynamite, as thus supplied, was made up into cartridges by the miners, an operation which was attended with inconvenience on account of the absorption of nitroglycerine by the hands, and its consequent unpleasant effects upon the system. For some time past, however, dynamite has been furnished to the trade in the form of small cylindrical cartridges, consisting of the material in a compact condition enclosed in a single wrapping of parchment paper. These cartridges are consolidated by pressure, whereby any excess of nitroglycerine which the porous earth will not hold absorbed is expelled, and thus the separation of nitroglycerine during handling, transport, or exposure to elevated temperatures, appears effectually guarded against. The consistency of the dynamite charges is like that of dry putty, and the fingers are scarcely soiled with nitroglycerine when the uncovered charges are handled.

The kieselguhr selected as the medium for the application of nitroglycerine appears the material best calculated to hold absorbed a large proportion of the liquid, and to retain it even when the mixture is submitted to considerable pressure. When dynamite factories were established in the outskirts of Paris during the late siege, and this particular siliceous earth could not be procured, a series of experiments was instituted for the purpose of discovering a good substitute; the most efficient absorbents next to this material were found to be precipitated silica, kaolin, tripoli, precipitated alumina, and sugar; but none of these appeared thoroughly equal to kieselguhr in their power of retaining a very large proportion of the oil.* Indeed, no other preparation has hitherto been proposed containing so large a proportion of nitroglycerine so safely applied as Mr. Nobel's so-called No. 1 dynamite. Another form known as No. 2, and con-

* The ashes of Boghead coal, as the best substitute for kieselguhr, were eventually used for the production of dynamite during the siege.

taining a much smaller proportion of nitroglycerine, mixed with finely powdered saltpetre and resin, or coal, is manufactured by Mr. Nobel as a cheaper blasting agent, for employment when the violent crushing and rending action of the stronger dynamite is not required.

Since the idea of incorporating nitroglycerine with solid substances was first conceived by Nobel, several preparations of that substance have been devised, in all of which the porous silica has been partly or entirely replaced by solid substances of an explosive or semi-explosive character. Among these, the following may be named as having received some amount of practical application: Colonia powder, which consists of a modified gunpowder, saturated with nitroglycerine, and is therefore very similar to the first nitroglycerine preparation devised by Nobel; Horsley's blasting powder, which consists of his chlorate of potash and nut-gall powder impregnated with 20 per cent. of nitroglycerine; Dualine, which may be described as Schultze's sawdust powder impregnated with nitroglycerine; and Glyoxiline, which consists of a mixture of gun-cotton pulp and saltpetre, converted into porous pellets, which are saturated with nitroglycerine, and afterwards coated with varnish or other protective materials. It need scarcely be said that all these preparations partake to some extent of the properties of the original dynamite, though they differ considerably in their nature; they all, however, consist entirely of explosive materials.

The preparation called Lithofracteur, which was to some e tent used for purposes of demolition by the Germans during the late war, and with which experiments have been made in this country, is similar in composition to the substance already spoken of as Nobel's No. 2 dynamite; it contains a considerably smaller proportion of nitroglycerine than the original dynamite, and the kieselguhr in the latter is partly replaced by materials constituting of themselves a feebly explosive mixture.

One great defect of some of these nitroglycerine preparations, added to that of their great tendency to freeze, consists in the liability of the nitroglycerine to exude when they are subject to summer temperatures, or to considerable fluctuations of temperature. This property, which obviously constitutes a source of inconvenience and danger, has led the special Government Committee on Gun-cotton, who have lately investigated the properties of these preparations, to prescribe practical tests for the purpose of affording reliable means for determining their comparative safety in this respect.

In discussing the merits, as a mining and blasting agent, of gun-cotton in its most recent (compressed) form, the employment of this material was considered in an earlier part of this Paper, under precisely the same conditions as are fulfilled in the employment of powder. Compressed gun-cotton was, however, found by Mr. E. O. Brown, in 1868, to be susceptible of violent explosion through the agency of a detonation, like nitroglycerine and its preparations, one point of difference being that a more powerful and sharper detonation is required in the case of gun-cotton. When employed in the compressed form in this manner, gun-cotton becomes analogous, in its behaviour and effects as an explosive agent, to nitroglycerine; but the latter, in its pure condition, still appears to remain the more violently explosive substance. In ordinary blasting and quarrying operations where small charges are employed, the detonation of gun-cotton does not appear to present decided advantage over its explosion in the ordinary way, except in so far that hard tamping may be dispensed with, and that unsound holes may be successfully blown by detonation, while gun-cotton otherwise applied would probably fail in them. But in the employment of large charges, in submarine operations, in works of demolition, and others of a military class, the explosion of gun-cotton by detonation presents important advantages, because its strong confinement may be entirely dispensed with, and, as in the case of nitroglycerine and its preparations, with some waste of power it may readily be made to operate most destructively without any confinement whatever. Thus the rapid destruction of works and buildings, of stockades or bridges, the disintegration of boulders or other large masses of rock, the breaking up of guns and other masses of metals, may be alike expeditiously accomplished by compressed gun-cotton and by nitroglycerine, dynamite, and similar preparations, the charges being either completely unconfined, or introduced into perforations which may be left open.

It may be expected that some definite statement should be given of the comparative effects, as mining and blasting agents, of gunpowder and of the violently explosive materials which have been more especially referred to. Excluding nitroglycerine in its pure or liquid form as pre-eminently dangerous, and therefore only likely to receive exceptional application, and taking dynamite and compressed gun-cotton as fairly representing the really useful explosive agents of the violent class, it may be stated, generally, that in all operations where rapid destruction is to be accomplished, as in the instances just referred to, gunpowder is incontestibly inferior to those explosive agents. Not only would a much larger quantity of powder be required to produce similar results, but, in some instances, it would be impossible to perform the same operations even with exorbitantly large charges of powder. This is especially the case in the breaking up of masses of hard rock or metal by the superposition, or simple insertion into cavities, of the explosive agent. Again, in tunnelling and blasting in hard rock, the new explosive agents represented by dynamite and gun-cotton possess undoubted advantages. Important economy is effected by their use, not simply in regard to cost of material to produce equal effects, but also in regard to saving of labour, of tools, and of time. Short charges and long tamping (which need not be hard tamping) insure the breaking up of the hole to the bottom, and generally tend to break up the rock beyond the bottom of the hole. The holes may be of smaller diameter, and are more rapidly loaded; the latter being especially the case with holes which are horizontal or driven at an upward angle.

Practical experience with compressed gun-cotton in North Wales—and this, no doubt, also bears upon the employment of dynamite—has shewn that in tunnelling in the slate quarries, where sixty shillings per yard has to be paid when gunpowder is used, the same quantity of work can be done, and in less time, for forty-five shillings per yard.

The shattering and splitting effect of dynamite and gun-cotton in hard rock is much greater than with powder, but, in quarrying, the rock is generally not thrown off by them to the same extent. It is frequently found advantageous, in rapid working, to drive large and deep holes far back from the face, and charge these with the violent explosive, by which the rock is extensively fissured; large quantities of powder are then poured into the fissures, and by its explosion enormous quantities of rock are removed. In submarine blasting, a similar mode of combining the shattering and displacing effects of the violent and gradual explosive agents has been found very advantageous. In submarine demolitions, as in the destruction of wrecks, the violent explosives generally have a decided advantage; but in some operations upon iron ships, it has been found that the lifting effect of large charges of powder is advantageous in clearing away framework and other parts which have been shattered, but not actually removed, by the more violently explosive agents.

When a moderate cleaving and separating effect is required, accompanied by as little local action as possible, gunpowder cannot at present be advantageously replaced; as, for example, in the raising of large blocks of the finest slate. In other instances, of less frequent occurrence in industrial works, but which may be of some importance in military operations where great displacing action is required, gunpowder has the undoubted advantage. In the submarine blasting of very soft rock, such as soft limestone or chalk rock, the comparatively instantaneous action of the violent explosives operates disadvantageously in regard to their displacing power. As an illustration of this, some experiments made under Mr. Hawkshaw's direction in June, 1870, upon the foreshore near the Shakespeare tunnel, at Dover, may be referred to. The object was to ascertain whether the detonation of gun-cotton charges, placed upon the surfaces of submerged soft chalk rock, would break up the latter to such an extent as to facilitate its rapid removal by dredging. The results showed that the rock was completely disintegrated, or pounded into a plastic mass like clay, within a comparatively limited area; but that the shattering or rending of the rock did not extend to any considerable distance, as it would have done in the case of hard rock, of which the portions contiguous to the charge would have presented greater resistance to the blow exerted by the extremely rapid explosion. Numerous experiments made in this and other countries with gun-cotton and dynamite have shown that the violence of the concussion due to the suddenness of the explosion give materials of this class important advantages over gunpowder for use in submarine mines.

Though it may be comparatively easy to point out, in general terms, the peculiar practical advantages which these violent explosive agents possess over gunpowder, it is exceedingly difficult, indeed, impossible, in the existing state of knowledge, to give any precise information as to the equivalents of such materials as dynamite, gunpowder, gun-cotton, &c., or to state, even in regard to special applications, how much of the stronger explosive is really equivalent to a given weight of gunpowder or of some other material. Such statements are, however, constantly made, and with great confidence; thus the author has even heard a particular nitroglycerine preparation spoken of as having, in some rough experiments, produced a result ten per cent. better than that of another similar preparation. The serious difficulties have already been referred to which attend any attempts to institute a strict comparison between the destructive effects of different explosive agents, and there can be no doubt that, at any rate at present, long continued use of two materials in the same class of work can alone determine their relative merits by the average results furnished. With regard to dynamite and compressed gun-cotton, it may be stated generally, but with reserve, that in ordinary blasting operations, the results furnished by them, weight for weight, are accepted as being about six times those produced by gunpowder. In comparing the effects of dynamite containing 75 per cent. of nitroglycerine with those of gun-cotton, the two materials appear to be practically on an equality as regards power, weight for weight; but dynamite has this advantage, which is shared by similar preparations, that in rugged and uneven holes, a somewhat larger charge can be introduced into a given length of hole, because its plasticity permits of its being made by gentle pressure to completely fill the space allotted to the charge, while the rigid gun-cotton will not accommodate itself to irregularities in the shape of the hole. With regard to other special advantages of either of the explosives named, the most prominent one of dynamite is, that it may be used in a damp hole without fear of its missing fire; while, on the other hand, compressed gun-cotton possesses the advantages that it is not in any way injurious to handle; is not at all affected in its ready explosiveness by cold; and may, if necessary, be preserved for any length of time, without deterioration, in the damp and perfectly unignitable state. Before the compressed material is stored, and immediately after its removal from the presses in which it is converted into discs or slabs, it is allowed to soak in water for a few minutes, so as to absorb about 25 per cent., and in this wet and absolutely uninflammable condition it is packed into wooden cases with well-fitting lids and lined with a waterproof preparation of gutta-percha and pitch. Gun-cotton may be preserved, either immersed in water or saturated with that liquid, for any period without change, and the absolute safety of the above simple method of storage has been established by experiments on a large scale. Two strong brick buildings each containing 20 cwt. of moist gun-cotton, packed in the usual manner, were filled with combustible material, which was then inflamed. The contents of the building were gradually consumed, the compressed gun-cotton burning away slowly as the surfaces became sufficiently dry to be ignitable. Similar experiments conducted with buildings containing comparatively small quantities (6 cwt.) of dry gun-cotton (and of dynamite) resulted, in some cases, in violent explosions, some portion of the material being raised to the exploding temperature before any considerable quantity had been burned. The great advantage, in point of safety, of preserving gun-cotton in the wet state was thus convincingly demonstrated. The drying of the substance, with the aid of steam, is a simple operation, which can be conducted expeditiously at the localities where it is to be employed, but the necessity for this operation has recently been much diminished, as will presently be shown.

With regard to the vapours evolved by gun-cotton and dynamite in underground work, there is no question that both possess the advantage over gunpowder, and explosive mixtures analogous to it, of producing but little smoke; but if a hole should be overcharged, or if the explosion should be imperfect from any cause, then the vapours evolved in both instances are decidedly more objectionable than gunpowder-smoke.

Moreover, in the case of gun-cotton, a large proportion of carbonic oxide is evolved, even by its most perfect explosion, which not only imparts a more actively poisonous character to the products of explosion, but also is liable to cause considerable inconvenience if the material is used on a large scale in underground operations, as in military mines, by giving rise to after-explosions, occasioned by the accidental ignition of the explosive mixture, which that gas will form with the air in the galleries or shafts. This difficulty is not likely to be experienced, however, in the employment of a gun-cotton preparation recently experimented with (nitrated gun-cotton), which will be again further referred to.

In the course of the systematic experiments lately carried on by the War Office Torpedo Committee, for the purpose of comparing the explosive force developed under equally favourable conditions of submersion and confinement of different explosive agents, it was found that the force, as registered by means of "crusher-gauges," which was developed by Nobel's dynamite, was nearly equal to that of dry compressed gun-cotton, but decidedly inferior to that resulting from the detonation of the *wet* compressed material (the properties of which will be presently discussed).

Among the results of the experimental enquiry which the author commenced five years ago, with the view of throwing light upon the nature and causes of the phenomena exhibited by nitroglycerine and gun-cotton, when submitted to the action of a detonation, was the observation that all explosive compounds and mixtures, even including gunpowder, are susceptible of violent explosion through the agency of a detonation, though the nature and force of the required detonation vary considerably with different explosive substances. It was found that the full explosive force of gunpowder could be developed without a close confinement of the charge, by the employment of a sufficiently powerful detonating fuze; and a series of experiments, instituted during the demolition of works by the Royal Engineers at Chatham and at Portsmouth, indicated that decided advantages were attained by employing detonating fuzes for the explosion of charges of gunpowder which were not strongly confined. In submarine operations, the advantage of using detonating fuzes with gunpowder has been even more manifest, it being decisively proved that by their use the full explosive force of a large charge of powder could be developed without employing the very strong receptacles required for insuring its complete ignition when fired in the ordinary way. Some interesting results were also obtained in blasting experiments with gunpowder, in which the charge was ignited at different distances from the top, and which indicated that, in blast holes of considerable depth, decided advantage was gained by igniting the charge at or near the base, as the upper part then acted as additional tamping to the portion first ignited, and thus considerably increased the violence of the explosion.

The manner in which a detonation operates in determining the violent explosion of gun-cotton, nitroglycerine, &c., has been the subject of careful investigation. It has been demonstrated experimentally that the result cannot be simply ascribed to the direct operation of the heat developed by the chemical changes of the charge of detonating material used as the *exploding* agent. An experimental comparison of the mechanical force exerted by different explosive compounds, and by the *same* compound exploded in different ways, has shown that the remarkable power possessed by the explosion of small quantities of certain bodies (the mercuric and silver fulminates) to accomplish the detonation of gun-cotton, while comparatively very large quantities of other highly explosive agents are incapable of producing that result, is generally accounted for satisfactorily by the difference in the amount of force brought to bear suddenly upon some portion of the mass operated upon. Most generally, therefore, the degree of facility with which the detonation of a substance will develop similar change in a neighbouring explosive substance may be regarded as proportionate to the amount of force developed within the shortest period of time by that detonation, the latter being, in fact, analogous in its operation to that of a blow from a hammer, or of the impact of a projectile.

Several remarkable results of an exceptional character have, however, been observed by the author, which indicate that the development of explosive force, under the circumstances referred to, is not always ascribable to the sudden operation of mechanical force. These were especially observed in the course of a comparison of the conditions essential to the detonation of gun-cotton and nitroglycerine by means of particular explosive agents (such as the chloride of nitrogen), as well as in an examination into the effects produced upon each other by the detonation of those two substances, nitroglycerine being *very* susceptible of explosion by gun-cotton, while the detonation of the latter can only be accomplished by comparatively large quantities of nitroglycerine. The explanation offered of these exceptional results is to the effect that the vibrations attendant upon a particular explosion, *if synchronous* with those which would result from the explosion of a neighbouring substance in a high state of chemical tension, will, by their tendency to develop those vibrations, either determine the explosion of that substance, or, at any rate, greatly aid the disturbing effect of mechanical force suddenly applied; while, in the instance of another explosion, which developes vibratory impulses of different character, the mechanical force applied through its agency has to operate with little or no aid; greater force, or a more powerful detonation, being, therefore, required in the latter instance to accomplish the same result.

Instances of the apparently simultaneous explosion of numerous distinct and even somewhat widely separated masses of explosive substances (such as simultaneous explosions in several distinct buildings at powder mills) do not unfrequently occur, in which the generation of a disruptive impulse by the first or initiative explosion—which is communicated with extreme rapidity to contiguous masses of the same nature—appears much more likely to be the operating cause, than that such simultaneous explosions should be only brought about by the direct operation of heat and mechanical force.

The foregoing view has been favourably entertained by many, as affording a reasonable explanation of the apparently anomalous results referred to, and has received support from the results of experiments recently instituted by Champion and Pellet, with iodide of nitrogen and some other explosive compounds, which indicated that the explosion of certain sensitive substances could be accomplished only by vibrations of a particular pitch, and by which they also demonstrated that particular explosions affected certain sensitive flames which were unaffected by others, unless the volume of the explosion was proportionately much increased.

Some few experiments were made by Champion and Pellet on the transmission of detonation to iodide of nitrogen through considerable spaces, by means of tubes, and some experiments of a purely practical character have also been instituted by Captain Trauzl, of the Austrian Engineers, on the transmission of detonation to cartridges of dynamite, separated by spaces, in iron tubes, by the explosion of a charge of the material placed in one extremity of the tube. It appeared to the author that a systematic investigation of the transmission of detonation through the agency of tubes, with the employment of explosive agents less highly susceptible and more uniform and constant in composition than the iodide of nitrogen, might usefully contribute to our knowledge of the behaviour and relation to each other of explosive substances.

Experiments were first carried on with tubes of cast and wrought iron of different diameters and lengths. The explosive agents used were gun-cotton, in different mechanical conditions, dynamite, mercuric fulminate, and preparations containing the latter as an ingredient. Interesting results were obtained, among others, in the course of these experiments, demonstrating a want of reciprocity in behaviour between gun-cotton and mercuric fulminate, as regards the transmission of detonation from one to the other, similar to that previously observed in the case of nitroglycerine, chloride of nitrogen, and gun-cotton, and showing also how greatly the results, as regards transmission of detonation, may be altered when certain limits, in respect to the quantity of material employed as the initiative detonator, are exceeded.

A few experiments were made on a comparatively large scale with the above-named explosives, with the view of ascertaining the influence of *the material composing the tube*, upon the effect produced; and some striking results were also obtained by interposing very slight obstacles (*e.g.* loose tufts of cotton wool) in the path of the gas-wave, and thus checking the transmission of detonation, which was certain when the path was unobstructed. But these points were more closely investigated by a series of accurate experiments upon a small scale with silver fulminate, the tubes used being alike in diameter and thickness, but varying in length, and consisting of different materials, viz., glass, pewter, brass, paper, and vulcanized india-rubber. The principal results obtained by the larger operations with other explosives were confirmed by these small experiments and several additional interesting observations were made. A great difference appeared at first to be established in the power possessed by tubes of different materials of favouring the transmission of detonation, the glass tubes being far in advance of the others in this respect. It was eventually established, very clearly, that this difference was not due, to any decisive extent, to the physical peculiarities (in regard to sonorosity, elasticity, &c.) of the materials composing the tubes, but chiefly to differences in the degree of roughness of their inner surfaces, and in the consequent variation of the resistance opposed by those surfaces to the gas wave. Thus the power of a glass tube to favour the transmission of detonation was reduced, by about two thirds, by coating the inner surface with a film of French chalk, while the facility of transmission through a brass tube was nearly doubled by polishing its interior, and was increased threefold, with a paper tube, by coating the interior with glazed paper.

The following are some of the points established by these experiments on the transmission of detonation by tubes :—

1. The distance to which detonation may be transmitted through the agency of a tube, to a distinct mass of explosive substance, is regulated by the following conditions:

(*a*) By the nature and the quantity of the substance employed as the initiative detonator, and by the nature of the substance to be detonated, but not by the quantity of the latter, nor by *the mechanical condition* in which it is exposed to the action of the detonation ;

(*b*) By the relation which the *diameters* of the " detonator," and of the charge to be detonated, bear to that of the tube employed;

(*c*) By the strength of the material composing the tube, and the consequent resistance which it offers to the lateral transmission of the force developed at the instant of detonation ;

(*d*) By the amount of force expended in overcoming the friction between the gas and the sides of the tube, or other impediments introduced into the latter;

(*e*) By the degree of completeness of the channel, and by the positions assigned to the detonator and the charge to be detonated.

2. The nature (apart from strength or power to resist opening up, or disintegration) of the material composing the tube through which detonation is transmitted, generally appears to exert no important influence upon the result obtained. At any rate the differences with respect to smoothness of the interior of the tubes far outweigh those which may prove traceable to differences in the nature of the materials composing them.

Results of practical value appear likely to emanate from the readiness with which detonation may be transmitted from one portion of gun-cotton or dynamite to distant and widely separated masses, confined in a strong tube or channel. Some blasting experiments in solid masonry at Gillingham, and some tunnelling operations carried on by the author in conjunction with Major Beaumont, Royal Engineers, demonstrated that considerable economy in explosive material and in the time and labour required for charging blast-holes, can be effected by dividing the explosive material into small distinct charges placed at some distance from each other in the blast-hole, their practically simultaneous explosion being accomplished by detonating a small charge in the upper end of the hole.

In the tube experiments with gun-cotton many instances occurred in which the mass operated upon was *exploded*, but with comparatively little, if any, destructive effect, portions of the gun-cotton being at the same time dispersed and occasionally inflamed. Similarly, the mercuric fulminate was frequently exploded, through the agency of a transmitted detonation, in a manner quite distinct from the violent *detonation* at other times developed. Even the silver fulminate, which under all ordinary circumstances detonates violently even when only one particle of a mass is submitted to a sufficient disturbing influence, was on one or two occasions exploded by the transmitted effect of a detonation of mercuric fulminate, without the usual destructive effect.

This remarkable difference in the behaviour of one and the same explosive substance, under nearly similar circumstances, has been made the subject of experimental investigation, in the course of which some interesting illustrations have been obtained of the manner in which variations in the resistance to mechanical motion influence the results obtained, by submitting some parts of a mass of explosive material to sharp blows, by firing from a rifle (at different ranges) against masses of compressed gun-cotton of different weight and thickness, and either freely suspended in air or supported in various ways. An important exemplification of the difference between explosion and detonation was obtained in the course of subsequent experiments, instituted for the purpose of determining the velocity with which detonation is transmitted through tubes.

The influence of dilution, by solids and liquids, on the susceptibility of explosive compounds to detonation has been made the subject of systematic experiments, and some of the results obtained have already acquired considerable importance. The dilution of a liquid and of a solid explosive compound by inert solid substances produces very different results. Thus the liquid (nitroglycerine) may be very largely diluted (as in the case of *dynamite* and similar preparations) by inert solids, without any modification of its sensitiveness to detonation, because this dilution does not interrupt the continuity of the explosive substance. The initiative detonator, when surrounded by such a mixture, is therefore in contact at all points with some portion of the nitroglycerine, and the latter is in continuous connection throughout; hence detonation is as readily established and transmitted through the mixture as though the liquid were undiluted. But when a *solid* explosive agent is similarly diluted, there must obviously be complete separation of its particles at a number of points proportionate to the extent of dilution and the state of division; the establishment of detonation, or its transmission, is therefore impeded either by a diminution of the extent of contact between the initiative detonator and the substance to be exploded, or by the barrier which the interposed non-explosive particles oppose to the transmission of the detonation, or by both causes.

Intimate mixtures of a finely divided sensitive explosive compound with an inert solid, if compressed into compact masses, become much more susceptible of detonation than if they be in the loose pulverulent condition; thus compressed mixtures of finely divided gun-cotton, with large proportions of inert solids, were found but little inferior in sensitiveness to the undiluted explosive agents. If the diluent consists of a soluble salt (*e.g.* potassium chloride) the well-incorporated mixture being compressed with the aid of the solvent (*e.g.* water), and then dried, the material is obtained in a condition of great rigidity, the particles being cemented together by the crystallized salt; it is therefore in a form more favourable to the action of detonation than undiluted gun-cotton submitted to considerably greater compression.

When the solid substance with which gun-cotton is diluted consists of *an oxidizing agent* (a nitrate or chlorate), the predisposition to chemical reaction between the two substances so far increases the susceptibility to detonation that, operating in conjunction with the effect of the soluble salt in imparting rigidity to the mixture, it renders the latter quite as sensitive to the detonating action of the minimum fulminate-charge as undiluted gun-cotton is, when highly compressed. This fact has given additional importance to results which the author obtained some time since in availing himself of the facility with which finely divided gun-cotton, as obtained by the pulping process, may be intimately mixed with the proportion of an oxidizing agent (such as saltpetre) required to completely oxidize the carbon. If about three-fourths of the theoretical requirements of the salts be employed, the resulting products will perform fully the amount of work obtained from a corresponding weight of undiluted gun-cotton; and as nearly one-third of this substance has been replaced in them by material of very much less cost, a considerable advantage is gained in point of economy. Moreover, the greater rigidity of the compressed masses of "nitrated" gun-cotton, already explained, renders them less susceptible to injury by transport and rough usage than ordinary compressed gun-cotton.

These compressed mixtures being found quite as sensitive to detonation by fulminate as the pure explosive compound, it became interesting to compare their behaviour with that of the latter, when exposed to the detonation of nitroglycerine. The results demonstrated that they are much more readily susceptible of detonation by it than compressed gun-cotton; thus, in only one instance was the latter detonated by the explosion of two ounces of nitroglycerine in close contact with it, but that quantity invariably detonated "nitrated" gun-cotton. The same result was obtained with only one ounce of nitroglycerine in three out of four experiments; in the fourth the nitrated preparation was *exploded*, but without the destructive effect produced in the other experiments; similar explosions of the substance were developed by means of 0·5 ounce of nitroglycerine. In the case of pure gun-cotton, the results obtained were always either simple disintegration of the mass, or else detonation, if sufficient nitroglycerine were used.

To ascertain whether the different behaviour of the "nitrate" (and "chlorate") preparations was due to their greater hardness and rigidity, some corresponding experiments were made with compressed masses produced in a precisely similar manner, but containing an inert salt—potassium chloride—in the place of the oxidizing agent. These were more susceptible of explosion by nitroglycerine than pure gun-cotton, but decidedly less so than the "nitrate" preparations. It appears, therefore, that the explosion of gun-cotton by the detonation of nitroglycerine is, to some extent, facilitated by the greater resistance it opposes to disintegration when incorporated with a salt, as described; but that the higher susceptibility to detonation by nitroglycerine of the "nitrate" (and "chlorate") preparations is probably chiefly due to some predisposing influence exerted by the oxidizing agent.

A number of comparative experiments have been instituted by the Gun-cotton Committee with the ordinary compressed gun-cotton and the nitrated material, and the conclusions arrived at from the results obtained are that a given *weight* of nitrated gun-cotton is fully equal in destructive power to a corresponding weight of the ordinary compressed material; and that when equal *volumes* are employed, the nitrated material is very decidedly superior to the other. As about one-third of the weight of gun-cotton in a given mass is replaced in nitrated gun-cotton by a substance of about one-sixth its cost, it is evident that the nitrated form presents economical advantages. When, however, great *suddenness* of explosion is important, the ordinary compressed gun-cotton is very decidedly superior to a *corresponding weight* of the nitrated material. This has been conclusively demonstrated by some recent experiments of the Torpedo Committee.

If gun-cotton is diluted by impregnation with a *liquid*, or with a body solid at ordinary temperatures, introduced as a liquid into the mass, such as a fat, its sensitiveness to detonation is reduced to a far greater extent than by a corresponding weight of a solid, incorporated *as such*, with the gun-cotton. The cause of this is evidently the converse of that which operates in preventing the reduction of sensitiveness of nitroglycerine by its considerable dilution with an inert *solid;* the liquid *diluent* which envelopes each particle of the solid explosive material isolates it from its neighbours, and thus opposes resistance to the transmission of detonation, while with nitroglycerine the liquid *explosive agent* envelopes the solid diluent, and thus remains continuous throughout the mass.

The absorption of three per cent. of water by gun-cotton (in addition to the two per cent. which it normally contains) rendered its detonation doubtful by the "detonator" ordinarily used. Dry discs which had been impregnated with oil or tallow, could not be exploded by means of 15 grains of mercuric fulminate, applied in a metal case in the usual way. By considerably increasing the initiative charge of fulminate, damp gun-cotton could, however, be detonated; and it occurred to the author's assistant, Mr. E. O. Brown, to apply the detonation of dry guncotton itself to the development of the explosive force of the compressed material, when in a moist state.

A series of precise experiments showed that when compressed gun-cotton contained as much as 17 per cent of water, it could be detonated, though not with absolute certainty, by 100 grains of compact air-dry gun-cotton exploded by means of the usual "detonator," in close contact with it. When the proportion was increased to 20 per cent., detonation was not accomplished with certainty by employing less than one ounce of the air-dry material; and when the maximum amount of water (30 to 35 per cent.) was absorbed, detonation could not be absolutely relied upon with the employment of less than 4 ounces of air-dry gun-cotton applied *in close contact*.

Moist and wet compressed gun-cotton is decidedly more readily susceptible of detonation by means of air-dry gun-cotton, freely exposed and exploded by the usual "detonator" of mercuric fulminate, than by means of the confined fulminate applied alone; thus, when the material contained 17 per cent. of water, its detonation by fulminate direct was not certain with the employment of less than about 200 grains, whereas the result was absolutely certain with employment of about 150 grains of air-dry gun-cotton.

The transmission of detonation from dry to wet gun-cotton, through the agency of a tube, appears to take place with the same facility as though the mass to be detonated were dry; and the same is the case with regard to the propagation of detonation from one mass of moist gun-cotton to others freely exposed to air, but touching each other, provided the one first detonated contained *not less* water than the other to which detonation is to be transmitted; but this is not the case, if even small spaces intervene between the separate masses, and in this respect the moist gun-cotton behaves very differently from the air-dry material.

The "nitrated" and "chlorated" preparations of gun-cotton are as readily detonated, in the moist state, as ordinary compressed gun-cotton. With respect to the mechanical effects obtained by the detonation of these materials in the moist or wet state, numerous small and large comparative experiments have demonstrated that there is no falling off in the work done by them when used wet.

Decided evidence has, moreover, been obtained of greater sharpness of action, when gun-cotton and its preparations are detonated in the wet state; and this accords with the observations made in the earlier of these researches, that the less susceptible a mass of given explosive material is of compression, when submitted to the action of a sufficient initiative detonation, the more readily will detonation be transmitted, and the more suddenly will the transformation from solid to gas and vapour take place. When air is replaced by water in the compressed masses, the transmission of detonation is obviously favoured by the increased resistance of the particles to motion, at the instant of their exposure to the detonative force.

The comparative experiments recently carried on by the Torpedo Committee, at Stoke's Bay, as also some stockade experiments made at Upnor, in the summer of 1873, demonstrated conclusively that greater violence of action is secured by detonating the gun-cotton in a thoroughly wet condition; and some comparative experiments made by the Germans during the manœuvres at Graudenz, last autumn, showed that wet gun-cotton was equal to dynamite in its applications to purposes of demolition.

The freezing of wet compressed gun-cotton renders it as readily susceptible of detonation as the mixtures of gun-cotton with soluble (crystallized) salts, to which the wet material obviously becomes quite similar in structure by the solidification of the water.

Mercuric fulminate and mixtures of it with potassium chlorate, when mixed with water to such an extent as to convert them into pasty masses, and freely exposed, are readily detonated by small quantities (3 grains) of the confined fulminate, even when not in contact. Finely divided gun-cotton, made up into a pulp with water, was found not to be susceptible of detonation, even under very much more favourable conditions than the above, the mixture being placed in thin metal cylinders, open at one end, and a large disc of dry gun-cotton detonated in the centre. But if wet *compressed* gun-cotton is packed into receptacles of wrought iron, so that the initiative charge of dry gun-cotton is closely surrounded by it, and the small spaces intervening between the several masses are filled up with water, the charge being then submerged, it is exploded with certainty and with results equal to those furnished under similar conditions by the dry material. Provided the escape of force, by transmission through the water, be retarded at the instant of the first detonation, either by the resistance which the material of the case offers, or by the pressure of a considerable column of water, the detonation of wet gun-cotton immersed in water, and separated by thin layers of the fluid from the contiguous masses, is accomplished with certainty. Results fully equal to those furnished by charges enclosed in strong wrought-iron cases, have been obtained by the employment of sheet-tin cases or of bags, or even of simple fishing-nets, these only serving to hold the masses composing the charge tightly together. If, however, the latter condition is not attended to, or the depth of the immersion of the charge is insufficient, its detonation will not take place, even if a comparatively large initiative detonator be employed.

The suddenness and completeness with which detonation was transmitted through small water-spaces in the experiments with wrought-iron cases, led the author to attempt the application of water as a vehicle for the efficient employment of only small detonating charges for bursting or breaking up cast-iron shells into numerous and comparatively uniform fragments (and thus to employ a hollow projectile of the most simple construction to fulfil the functions of the comparatively complicated "shrapnel" or "segment" shell). The results afforded remarkable illustrations of the transmission of force by water, and may prove of considerable practical importance. The destructive effect produced by small detonating charges, when exploded in shells which were filled up with water and entirely closed, was proportionate, not simply to the amount of explosive agent used, but also to the suddenness of the concussion imparted to the water by the explosion. Thus, 0·25 ounce of compressed gun-cotton, detonated in a shell filled with water, broke it up into nearly eight times the number of fragments obtained by exploding a shell of the same kind full of gunpowder (viz., containing 13 ozs.)* When picric powder, which is also a very violent explosive agent, though much less sudden in its action, was detonated in one of these shells in the same way as the small charge of gun-cotton, 1 oz., or an amount four times greater than that employed of the latter substance, burst the shell into about the same number of fragments as were produced by the 13 ozs. of gunpowder (instead of about eight times the number, produced by means of 0·25 oz. of gun-cotton). Other observations of interest were made in the course of these shell-experiments; they led, moreover, to some cognate experiments which furnished interesting results.

In developing detonation, in a perfectly closed and sufficiently strong vessel, completely filled with water besides the detonating charge, the resistance offered by the liquid at the instant of detonation may be regarded as similar to that which would be presented by a perfectly solid mass. Similarly, if the strong vessel be completely filled with a mixture of water and a solid (*e.g.* a fine powder or a fibre reduced to a fine state of division), such a mixture should also, at the instant of detonation, behave as a very compact solid with regard to the resistance which it opposes to the detonating charge which it surrounds. If this be so, a mixture of finely divided gun-cotton with water, if enclosed in a shell, should be in a condition readily susceptible of detonation, because at the instant of explosion of the initiative charge, the particles of gun-cotton must offer great resistance to mechanical motion. Experiment has fully established the correctness of this conclusion, having demonstrated that, while it is indispensable to employ gun-cotton in a highly compressed form, to ensure its detonation under all other conditions, it may, if enclosed in strong vessels such as shells be employed with equal efficiency in a finely divided state, provided the spaces between the particles be *completely* filled with water, the small detonating charge being immersed in the aqueous mixture.

The results obtained in the several experiments bearing on the transmission of detonation, led the author to attempt to determine its velocity, or the rate at which it proceeds along a continuous mass, or from one mass of an explosive body to another, under various conditions. For this purpose he availed himself of the electric chronoscope devised by Captain A. Noble, F.R.S., which had furnished satisfactory results in determinations of the rate of motion of projectiles in the bore of a gun, made by the Government Committee on explosive substances. The experiments were carried out with compressed gun-cotton in the dry and wet state, with "nitrated" gun-cotton, with nitroglycerine and dynamite, and with small charges of gun-cotton inserted into tubes, with considerable intervening spaces. The discs of gun-cotton, dry, wet, and nitrated, were arranged

* Some recent experiments against targets at Shoeburyness, with shrapnel shells, and common shells charged with water and 0·25 oz. of dry gun-cotton, furnished results very decidedly in favour of the "water shells."

either in continuous rows or trains, the discs either touching each other, or a definite and uniform space or interval intervening between each. At the commencement of the row a fine insulated wire, forming part of the primary circuit (by the sudden severance of which the electric record of the rate of transmission was obtained on the chronoscope), was tightly stretched across the first disc. Other wires were similarly fixed at uniform distances (of one, two, four, or six feet) from each other. In determining the velocity of transmission of detonation through tubes, wrought iron gas-pipes of 1·25 inch diameter were used, with small perforations at the desired intervals, through which the insulated wires were passed; the discs of gun-cotton, to which detonation was to be transmitted, were inserted into the tubes so as to be in close contact with these tightly stretched wires. The trains of dynamite were arranged like those of gun-cotton, compressed charges of this material, 3 inches long and 1 inch in diameter, being placed end to end or with definite spaces intervening between them. The nitroglycerine was placed in V-shaped troughs of thin sheet metal, through which the insulated wires were passed transversely at the requisite intervals, so as to be immersed in the liquid.

A number of experiments with compressed dry gun-cotton demonstrated that the rate at which detonation is transmitted from mass to mass, when these are in actual contact with each other, is between 17,500 and 20,000 feet per second, and that the rate of transmission is affected by the compactness of the material, but not by a difference in the form and arrangement of the individual masses, nor by very considerable variations in their weight. By the experiments with *spaced* gun-cotton discs, it was demonstrated that the separation of the masses may retard the rate at which detonation is transmitted, the extent of such retardation being, of course, determined by the relation between the size of the individual masses and the extent of space intervening between them. With compressed gun-cotton, containing fifteen per cent. of water, detonation was transmitted at a slightly higher velocity than with the dry substance of the same compactness; but when gun-cotton *saturated* with water was employed, the increase in the rate of transmission was very marked, being equal to about 20,000 feet per second, with discs which, when dry, detonated at a rate of about 17,500 feet per second. With "nitrated" gun-cotton the rate of transmission was, as might have been anticipated, decidedly slower than with the pure dry material; it ranged between 15,500 and 16,000 feet per second.

The results obtained with dynamite and nitroglycerine presented some very interesting points of difference from those furnished by compressed gun-cotton, which are ascribable to the liquid nature of the explosive material. The dynamite used was in the form of compressed rolls or cylinders, similar in firmness or solidity to stiff but not very plastic clay. Rows or trains of these charges, pressed together end to end, so as to form perfectly continuous masses, 28 feet and 42 feet in length, were detonated by means of a fulminate detonator of the kind used with gun-cotton, which was inserted into a small cylinder of gun-cotton, or into a small cartridge of dynamite, and placed upon one extremity of the train. The rate at which detonation was transmitted ranged between

19,500 and 21,600 feet per second; it was, therefore, decidedly higher than with compressed gun-cotton. The separation of the individual cartridges or cylinders by spaces of 0·5 inch produced, however, a very much greater retarding effect than was the case with a separation to the same extent of masses of compressed gun-cotton; the mean rate at which velocity was transmitted along the spaced masses of dynamite (in an experiment remarkable for the great uniformity of the records at different parts of the train) was only 6,239 feet per second; the mean rate of transmission along masses of gun-cotton of the same weight and length of the dynamite cartridges, and separated by 0·5 inch spaces, was (in two experiments) nearly 17,000 feet per second. When *nitroglycerine* was employed in the pure, and, therefore, in the liquid state, detonation being established at one extremity of the trains by means of a cartridge of dynamite, the mean rate at which it was transmitted was only about 5,500 feet per second, the same result being obtained in two experiments, in one of which the quantity of nitroglycerine, in a given length of the train, was double that employed in the other.* It may be possible that, by very greatly increasing the quantity of nitroglycerine used, the rate of transmission of detonation would be increased; but there is no doubt that the mobility and elasticity of the liquid, and the consequent facility with which it yields to mechanical force when unconfined, act antagonistically to the transmission of detonation in a mass of *freely exposed* nitroglycerine. The author hopes that he may have the means and opportunity of extending these interesting experiments, by ascertaining the effect of confinement, both of nitroglycerine and gun-cotton, on the transmission of detonation along continuous masses of the explosive agent.

The uniform rate at which detonation is transmitted along rows of considerable length, composed of distinct masses of the explosive material, even when these are separated from each other by spaces, is very remarkable. With trains 40 to 50 feet in length, the rate at which detonation travelled along the last few feet was equal to that observed in the first portion of the train. This was not the case with the transmission of detonation, through *tubes*, to *widely separated* masses of gun-cotton. The time intervening between the detonation of the initiative charge at one extremity of the tube and that of the first distinct charge (separated by a space of 3 feet 3 inches) was somewhat variable, and ranged between 10,000 and 13,000 feet per second; the subsequent transmission, from charge to charge, along the tubes, proceeded at a tolerably uniform but considerably reduced rate, the average being 6,000 feet per second. In one experiment, with reduced charges, the detonation was transmitted, as usual, to the first three separate masses; but the fourth and succeeding charges, though they *exploded*, did not detonate; the tube containing them was uninjured at those parts, but the wires were severed at the seat of each charge, and the records obtained indicated that the *explosion* was transmitted from charge to charge at the rate of between 1,500 and 1,800 feet per second. These

* The amount of nitroglycerine employed in a given length of the train corresponded to that used in certain of the gun-cotton experiments, in which the rate of transmission of detonation ranged between 18,000 and 21,000 feet.

experiments with tubes showed that, when the relations between the amount of the explosive material, the diameter of the tube, and the space intervening between the charges are such as to ensure the transmission of detonation, its rate is about one-third of that at which it travels along a continuous mass, or continuous row of distinct masses, of the same material.

It is impossible, at present, to foretell the industrial and military advantages which may result from a continued careful study and judicious application of the laws relating to the development of explosive force through the agency of detonation.

F. A. A.

PAPER X.

REPORT ON THE DEMOLITION OF THE WRECK OF THE STEAMER "KATE," AT HARWICH.

By CAPTAIN M. T. SALE, R.E.

On Thursday, the 16th of May, 1873, I received orders to proceed to Harwich to relieve Lieutenant Ord, and to take over charge of the wreck of the "Kate."

The "Kate" was a small screw steamer about 90 feet long; she foundered during a storm in the winter of 1872-3, in a place about one mile N.N.E. of the Cork light-vessel, five miles outside Harwich Harbour, where the water at low springs is about $4\frac{3}{4}$ fathoms.

As she foundered almost in the course of the Harwich and Continental steam-packets, it was of importance that the wreck should be removed as soon as possible.

A buoy had been placed by the Trinity House to mark out the position of the wreck, and, moreover, the site was in a measure indicated by the "wake," or boiling up of the tide, which was visible down stream when the tidal current was running strong.

The position of the wreck, situated as it was in the open sea off the eastern coast, where the occurrence of smooth water is rare, and the strength of the tide, which completely prevented work except during the hours of fresh water, formed the principal difficulties to be contended with.

Civilian divers had been employed to recover the cargo (railway iron), but owing to the numerous difficulties they could not succeed in emptying the hold.

The position of the wreck with reference to the ebb and flow of the tide, was as shown in fig. 1, Pl. XXVII. It was slightly listed over to port, and the hold contained a considerable quantity of railway iron. The bottom of the sea was hard clay, tolerably free from sand.

The charges to be used were damp gun-cotton, fired by a primer of dry cotton, and contained in the R.E. Committee's waterproof bags. They were to be ten in number, arranged as shewn in fig. 2, and fired simultaneously, touching the ship's side, and as low as they could be placed.

The charges were made up as follows (fig. 3) :—First, two tension fuzes (detonator), were connected in continuous circuit, and inserted in discs of dry cotton to form the primer. The primer was enclosed in a small waterproof bag, and the inside of the neck of the bag was well smeared with india-rubber solution, and securely bound round the conducting wires with twine. The strength of primer employed was three discs to a 100-lb. charge, and two discs to a 50-lb. or 60-lb. charge. The priming charges were then inserted in large waterproof bags of vulcanized india-rubber, the charges of wet gun-cotton carefully filled in round the primers, and finally the necks of the bags smeared with india-rubber solution, and held together with the wooden screw clips in the usual manner. The bags were then securely bound round with spun-yarn in the ordinary way, so as to give attachment to the tripping line which connected the charges with each other, and which served to take the strain off the electric cable (fig. 4).

The cable used for the charge-connection was Hooper's core with single hemp serving.

The damp gun-cotton contained 20 per cent. of water.

The plan on which Lieutenant Ord was working, was as follows:—

1st. To survey the ship by the help of divers.

2nd. To prepare the charges.

3rd. To get a line made fast to the propeller and buoyed; that being the only point on the ship's bottom to which a rope could be attached.

4th. The charges were then to have been connected up and placed, the stern charge being slipped down the rope leading to the propeller, and the other charges being laid as nearly as possible as shown in fig. 5, and subsequently gathered in by the diver and placed as shown in fig. 2, a return line being used in lieu of earth, to obviate any chance of failure from the recurrence of a single leak in the cable.

Lieutenant Ord prepared to make the final junction at the spot, keeping the charges open until the last moment, so that there might be no joint whatever outside the charges.

On my arrival at Harwich, I found that the charges had been all made with the exception of the end ones at each side, which had been left open for the reason stated in the preceding paragraph.

Lieutenant Ord also reported that the stern had been buoyed in readiness for lowering the charges, and that a buoy had been placed to mark the bow.

A few hours after my arrival Lieutenant Ord left, and the same evening Corporal Pring, the senior non-commissioned officer, who understood thoroughly the position of the wreck, and who knew of all the arrangements which had been made, was ordered off to Chatham by telegram from the War Office.

On Friday and Saturday, 16th and 17th May, there was no prospect of work, as the wind was blowing fresh. On Monday, 19th, it was too rough for work, but I had the charges finally connected up in two groups of five each, leaving at either end of each group 45 feet of cable (sufficient to reach the surface) stoppered throughout to the tripping line.

In making up the charges in this way, I abandoned, as superfluous, the precaution above alluded to; for had I trusted to making up the charges at the moment of laying, the delay involved just at the critical time when every moment would have been of value, might probably have caused the whole operations to fail.

On Tuesday, 20th May, the wind fell, and as there was a prospect of work, I went out with the charges and whole apparatus, the diving gear being contained in a large rowing boat. On arrival at the site of the wreck, I found that though there was little or no wind, there was such a heavy ground swell from the N.E. as to prevent work, and moreover made the disheartening discovery that every one of the buoys attached to the wreck had disappeared, making it necessary to recommence the whole thing (except making up the charges) *de novo.*

From what I saw, I came to the conclusion that it was not practicable to lay the charges as proposed, and therefore modified the plan of work as follows :—

First, take the starboard group of five charges, fig. 6; slide the stern charge down a rope leading to the propeller, then with an ebb tide lay the starboard charges from a rowing boat, taking care to keep a slight strain on the tripping line, lay the charges up stream, and allow boat and charges to be swept down by the tide against the wreck, the stern charge having been previously fixed.

For the port group, fig. 7, get a heavy sinker in position at the bow on the bottom of the sea, slide the bow charge down a line to this sinker, and lay the charges with a flowing tide from a rowing boat as before.

On Thursday, 22nd, there was a calm, and the day was very suitable for work. First we had to grapple for the wreck; having got a secure hold for the grapnel, we moored the diving boat right over the ship, and the diver (2nd Corporal Falconer) went down, and was fortunately able to fix in a short time a line to the propeller, fig. 8. The line fixed, we hauled it tight, and slid the stern charge down it by means of a ring. The charge went at once to its proper place, and was secured there by the diver. This somewhat critical operation having been accomplished, the remainder of the charges were laid so as to come as nearly as possible alongside the ship at the starboard side. It unfortunately happened that one of the charges (No. 3 from the stern) fouled one of the broken uprights of the ship's starboard rail, and owing to the delay thus caused, we were prevented from doing more that day by the flowing tide, and had to leave the charges down, one end of the cable being carefully insulated, the other being bared for two inches. The cables and stern lines were buoyed, and profiting by the experience gained by the loss of so many buoys on former occasions, I used solid wooden buoys, so arranged as to show at low water only. Had it not been for this unfortunate foul, the whole of the charges might have been then and there laid, and fired in the first day's work.

There was no opportunity of working again until Tuesday, 27th May. By this time, feeling how much the work had been hindered by the use of too small a diving boat—thereby stopping work on any but the very calmest days—I procured a large decked lighter for use as a diving platform, and though on the 27th there was so much sea that we could not have worked from the boat previously in use, yet having once moored the lighter in its place, we were not much inconvenienced by the waves.

On this occasion we found all the buoys correct, and cleared the charges at the starboard side, putting them into their proper places; also having ascertained the position of the bow of the wreck as nearly as possible by sounding, we lowered a heavy sinker, and were fortunate enough (as proved by subsequent inspections of the diver) to hit off at the first trial the exact place wanted, viz. the bottom of the sea at the ship's bow. We were not able to do more this day, because at the outset much valuable time had been lost by one of our lighter mooring lines having fouled a submerged buoy. And it may here be remarked that, owing to the number of lines attached to and floating up from the wreck under water, and the jagged rails, stancheons, and other projections from the wreck itself, the work of the diver had become both difficult and dangerous. Moreover, the operation of mooring the lighter over the wreck was anything but easy, owing to the difficulty in avoiding getting foul of the wreck itself. We had now five charges placed on the starboard side, and everything in readiness for lowering the port charges.

The next day but one (26th May) we again went out; again a great part of the tide was lost by one of our anchors having dragged and fouled the wreck. However we succeeded in laying the port charges in the manner above described, sliding the bow charge right down to the sinkers. I was not able, owing to the strength of the tide, to send down a diver to adjust these charges accurately, but satisfied myself that they were approximately in their proper position.

The charges were now as shown in sketch (fig. 9). As at C and D, there were about 2 inches bare wire showing (to serve as earth), it only remained to join A and B with the firing cable by a tri-junction or three-way joint, taking the precaution to stopper the ends of both tripping lines securely to the armoured firing cable, so as to resist any chance of strain on the more delicate Hooper's core cable used for the charge connection.

The charges were then in divided circuit, which was considered a more suitable arrangement than firing the whole in continuous circuit.

The lighter containing the cable was now towed very slowly up stream with a very long tow-rope. When about 80 yards of cable remained to be paid out, the signal was given for the tug to anchor, and the lighter was warped up by the tow-rope to the exact distance required. By this means we were enabled to adjust our position without bringing any sudden strain on the firing cable.

We had also taken the precaution of attaching the end of the cable, near the wreck, to a strong line which was fast to the wreck, so as to avoid any possibility of dragging the charges out of their places. The total distance from the wreck at the time of firing was about 280 yards. The concussion felt was much less than would have been due to a single charge equal to the aggregate of the whole number.

The columns of water thrown up by each charge could only be distinguished just at the top of the columns, except in the case of one, probably the last laid on the port side, which might very probably have caught against the side of the wreck, and not quite reached the bottom. The columns thrown up by this one charge towered far above the rest.

Large quantities of *débris* were seen to have been thrown up by the explosion, and as amongst this *débris*, grease from the engine room, and cabin fittings, were found, I had little doubt but that the explosion had done its work effectually.

The next day I went out at low tide and had soundings carefully taken all over the site of the wreck. Though we at once detected the broken fragments lying all round the site where the ship had been, we could not, after careful search, detect any fragment which projected more than 5 feet above the bottom of the sea, thus giving a minimum depth of 3½ fathoms at dead low springs.

The charges were fired by means of Von Ebner's friction machine. When Captain Armstrong, who was present at the wreck on the 27th and 29th, endeavoured to improve the working condition of his machine by drying it in the warmth from the steam tug's boiler, it was found that though at first the electrical condition was improved, it soon fell off, and, subsequently, almost altogether failed.

Captain Armstrong then took the machine to pieces, and it was found that, owing to its originally flimsy and unworkmanlike construction, the slight warping, due to heat, had dissevered several of the contacts, and had caused one joint to become unsoldered. This was remedied, the defective contacts were adjusted, and joint soldered, when it was found that the working of the instrument was greatly improved.

The work being one of rather an exceptional kind, it may be well to add here the result of the experience gained up to this point.

Unsuitability of gear.

The gear, both cable and charge-bags, was much too light and fragile to withstand properly the rough usage inseparable from sea work.

A bag loaded with a 100lbs. damp gun-cotton, with cables, tripping lines and sinkers attached, is about as awkward a thing to handle in a boat at sea as can well be imagined. It was with the greatest difficulty that the bags were kept from injury; and in one case, spite of precaution in passing the charge over the gunwhale of the boat it was pierced through; fortunately, the injury was detected in time for repair.

Much of the delay in carrying out the work was due to the unsuitability of the tug diving boat and mooring gear. The boat first used was much too small, the tug was a single engine paddle vessel, which at times could scarcely be steered at all.

The arrangement of the charges was not sufficiently simple; placing ten charges for simultaneous firing, was an operation much more suited for still and smooth waters, than for open sea work in a strong tideway.

It is true that the arrangement succeeded; nevertheless, the risk of failure and loss of the charges was very great, and I cannot but think that if fewer and heavier charges in stronger cases, and with durable connecting cable had been used, and if suitable tugs and lighters had been supplied by the Trinity Board at the outset, the work might have been done at a less cost, in a quarter of the time.

The time of the year was very unsuitable. Day after day Lieutenant Ord was prevented from working by the prevailing N.E. winds; and moreover his progress was cramped by the necessity which then existed for giving three days notice of the explosion, a condition which would have involved that almost impossible contingency, the recurrence of three consecutive days of settled weather in an English climate.

The wreck having been shattered, and the work apparently finished, I returned with my party to Chatham (3rd June, 1873).

The Trinity Board were then requested to make a thorough examination of the fragments of the wreck.

They did so; and as the civilian diver in their employ reported that there existed an iron rib or stem-piece which had escaped my sounding, measuring 8 in. by 3 in. in section, and projecting upwards, to a height of 14 feet, it was considered necessary to explode another charge to destroy this rib, which would otherwise prove an obstacle to navigation.

Before doing anything in the matter, the Trinity Board were particularly requested to cause their divers to buoy securely this piece of iron, so that there might be no mistake as to its existence, position, or identity.

This having been reported as done, I left Chatham on Thursday, 10th July, on board the "Irene," taking with me the same detachment as before (one non-commissioned officer excepted), and the S.M.E. diving boat (which was towed astern) and arrived at the site of the wreck at 5 p.m. We found that the reported obstacle was not buoyed.

On Friday, 11th July, I requested the Trinity House officials to indicate the exact spot where the obstacle was said to exist. They did so, and got the bight of a line round it. Our diver (Corporal Falconer) then went down by this line, and found that there was nothing answering to the dimensions reported—only a few stumps of ribs sticking up out of a confused mass of wreckage.

To make quite sure, the whole of the wreck was swept by means of a weighted spar sunk to a certain fixed depth, and held in a horizontal position between the boats and drifted down over the site of the wreck (see fig. 12). It was then found that the two highest points of the wreck were at the stem and stern, the former about 21 feet and the latter 21 feet 6 inches below the surface at low water springs.

I then lowered a charge of 112 lbs. of wet gun-cotton on the highest point at the stern, and attached it securely and fired it. On again sounding, it appeared that the depth had been increased to 23 feet over the bow.

I then telegraphed to the Secretary of the Trinity Board to ask if they wanted more done, and in reply was requested to endeavour to increase still further the depth of the water over the fragments.

As it was late on Saturday before I received the answer, nothing could be done that day, but on Sunday morning, though it was blowing rather fresh from the S.W., we went out to the wreck and succeeded in getting a line round the highest projection at the stern.

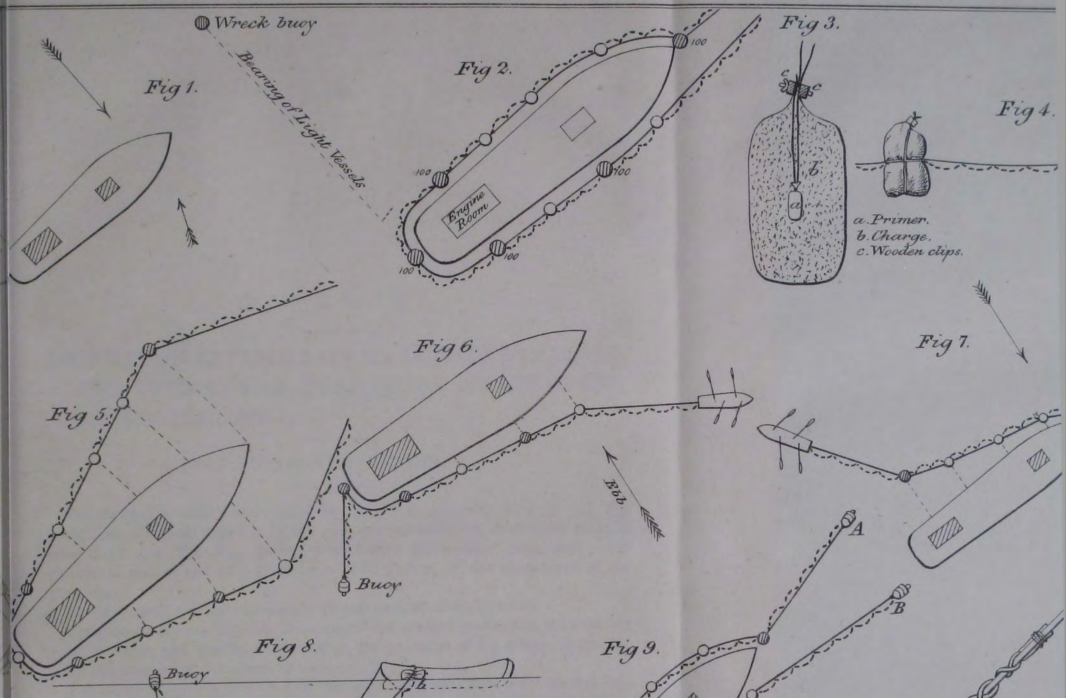
As the Trinity officials were sure that we had hold of the highest projection, and as it was blowing too fresh to send the diver down, I sent down a charge of 96 lbs , by sliding it down the tightened line (as before described), and ascertaining by sounding that it had reached the proper spot, fired it with the very satisfactory result of lowering the highest projection from 21 feet 6 inches to 25 feet depth, clear. As we now had a minimum of 23 feet clear over bow, and 25 feet over stern, in $4\frac{3}{4}$ fathoms of water (the midships being nearly flat) I considered that it would be a waste of work and materials to do more, and, therefore, returned direct to Chatham.

The whole of the sweeping was done by the Trinity House officials, and the depths given are those ascertained by them.

The presence of the Trinity steamer "Irene," was of the greatest possible assistance to me, and I quite believe that if the party had started, on the first occasion of going to the wreck, under the same favourabe conditions as on the second occasion, the whole of the work would have been done in a fortnight.

Throughout, the non-commissioned officers and men worked extremely well.

M. T. S.


Wreck buoy
Fig 1.
Bearing of Light Vessels
Fig 2.
Engine Room
100
100
100
100
100
100
Fig 3.
a. Primer.
b. Charge.
c. Wooden clips.
Fig 4.
Fig 5.
Fig 6.
Fig 7.
Ebb
Buoy
A
B
Fig 8.
Buoy
a. Propeller.
bbb. Charges.
Fig 9.
C
D
Tripping lines
Tripping lines
Fig 10
Fig 11.
Fig 12.
N.B. Electric cables shewn by chain dotted lines.

PAPER XI.

DEMOLITION EXPERIMENTS MADE WITH DYNAMITE, GUN-COTTON, AND GUNPOWDER, AT GRAUDENZ, IN AUGUST, 1873.

BY LIEUTENANT T. FRASER, R.E.

The dynamite used was supplied by Nobel; it appeared to be a stiff, dry stuff, like saw-dust caked with oil. It was contained in cartridges made of thin sheet zinc; the sizes generally used were 0·6 metres* long, and either circular in section and of a diameter of 0·03 metres, or else square and of the same size.

This dynamite was said to contain 60 per cent. of nitroglycerine.

The gun-cotton was English Government compressed gun-cotton, with 30 per cent. of water, and was fired with 300 to 400 grammes of dry cotton, detonated with 10 grammes of fulminate of mercury.

The experiments are described in the order in which they were carried out; and for convenience of reference, a list of them is given at the end, in a Table.

Experiment No. 1. A charge of 7·26 lbs. of dynamite was hung (at G, fig. 2, Pl. XXVIII.) against a wall of inferior masonry, with a loophole on each side of the charge; the effect was to blow away the wall before the charge for a width of 0.8 metres.

Experiment No. 2. A similar charge (7·26 lbs.) was placed at H, fig. 3, at the foot of the wall shewn in section in fig. 1; it failed to destroy the wall.

Experiment No. 3. A similar charge on the ground at I, fig. 3, cut a hole through the wall about 0·8 metres long.

Experiment No. 4. Two charges, each 7·26 lbs., were placed on the ground at J, fig. 3. The detonators were fired simultaneously by means of what is called "English fuze," which is a kind of Ord's fuze or hose, coated with india-

* A metre is roughly $3\frac{1}{4}$ feet; a kilogramme is 2·2 lbs.; a gramme is 1·543 grains.

rubber, so as to be useful under water. Both charges detonated together, and made a clear gap in the wall of 2 metres in length.

Experiment No. 5. Two cartridges, each 7·26 lbs. of dynamite, were placed, one at N, fig. 3, the other at K, and connected by a piece of soft metal gas-pipe of 8 milimetres internal diameter, and 6·25 metres long. The charge at N was then detonated, but it failed to detonate that at K. The pipe was not quite straight.

Experiment No. 6. Two similar cartridges (each with 7·26 lbs. of dynamite) at about 1 metre apart, were connected at L, fig. 3, with 1 metre of the same piping (with several cracks in it); one cartridge was detonated, and it detonated the other—the two destroying all the wall in front of them.

Experiments Nos. 7 and 8. Under each of the piers A, B, and C (fig. 4) were placed charges of 18 lbs. of powder; while under each of those marked D, E, F, (fig. 3) were placed 4 lbs. of dynamite, in cartridges 18 c. by 18 c. by 4·5 c. high.

All six charges were fired together by a dynamo-electric machine of large size. The six piers fell down. The *débris* over the powder were most moved, but were most broken up over the dynamite, which was as 1 to 4·5 by weight. The first six charges were fired with detonators and Bickford's fuze. These detonators are small copper caps, about 1 inch long and $\frac{1}{8}$th of an inch in diameter. A few drops of petroleum were poured into each, before the end of the fuze was inserted. The fuze was india-rubber covered, and burnt slowly. In no case did a fuze fail to detonate the dynamite.

Experiments Nos. 10 to 14 were made to test different forms of cartridges for dynamite, by destroying a brick wall with charges in cartridges of different shapes. (Figs. 20 and 21.)

Experiment No. 10. A charge of 16·5 lbs. of dynamite in a zinc case (size 0·6 m. by 0·09 m. by 0·09 m.) placed at the foot of the wall, as at A, fig. 23, and I, fig. 22. Result: destroyed the wall in front of it.

Experiment No. 11. The same weight of charge, 0·6 metres long, but as in fig. 20. In this case the effect was apparently the same, little, if anything, being gained by the difference of form of case.

Experiment No. 12. Three charges, each of 16·5 lbs., were placed at iii, fig. 22. The first case was 0·6 by ·09 by ·09 metres; the second case, 0·6 by ·05 by ·16 metres; the third case, 0·6 by ·05 by ·16 metres. The intervals between the cases were respectively, 0·1 and 0·2 metres; these, when detonated, formed a gap of 3·5 metres in the wall. The charges were on the ground.

Experiment No. 13. A charge, (fig. 21) of 22 lbs. of dynamite placed in a case (1·0 m. by 0·06 m. by 0·10 m.) lodged in a groove in the masonry at the foot of the wall at iv, fig 22; the explosion destroyed all the wall in front of the charge.

Experiment No. 14. A charge of 22·5 lbs. of dynamite at v, fig. 22, in a case (1·0 m. by 0·6 m. by 0·10 m.) placed as in fig. 20, cut down all the wall in front of the charge.

These experiments did not give much information as to the best shape of cartridge, as all the charges were capable of destroying the wall.

Experiments with dynamite against *Masonry, &c.*

Experiment No. 15. A charge of 100 grammes (154·3 grs. av.) of dynamite was placed in a cartridge at A, fig. 7, just above the lock of a sallyport gate. The lock was completely smashed, and the framing of the gate partly broken through.

Experiment No. 16. A charge of 13·2 lbs. of dynamite in a circular cartridge (60 c. by 9 c) was placed at B, at the foot of the wall (figs. 5 and 6); when fired, it blew away the masonry between the two loopholes, leaving the portion above the top of the loopholes still standing.

Experiment No. 17. A similar charge (13·2 lbs.) of dynamite in a cartridge square in section, and of the same volume and length as the first, was laid at C (fig. 5); five sandbags were placed over the charge, which, when fired, produced just the same effect as before. Bickford's fuze and detonators were used to fire it with.

Experiment No. 18. Three charges, each of 13·2 lbs. of dynamite were placed (D, fig. 5) in cartridges 8 c. square and 60 c. long, laid in a trench; the trench was about 12 inches wide and deep, and the cartridges were at intervals of 30 c. and 40 c., respectively; the whole of the charges were covered with earth. The effect was to blow away all the wall before the charges, the gap being about 3·5 metres wide.

Experiment No. 19. Three charges each of 8·25 lbs. of dynamite were placed in a groove at the foot of the wall as at E (fig. 5), the groove being 3·15 metres long, and the charges being in cartridges each 40 c. in length. A little earth was thrown up against the foot of the wall, so as to close the mouth of the groove. The effect of the charges was completely to destroy all the wall to their front and to the right hand end. The cartridges in all the above cases (except No. 15) were of sheet zinc.

Experiment No. 20. Several charges of dynamite were placed in the centre of a wall, as shown in fig. 8, and it was attempted to fire them in continuous circuit with a dynamo-electric machine; this failed, however, and they were afterwards fired separately with Bickford's fuze and detonators, one charge (placed at F, fig. 8, of 1·65 lbs.) completely demolished the wall around it. The results of the others were indefinite, owing to the wall having been patched and made up from a thickness of 1·0 metre to 1·9 m.

Experiment No. 21. This was a comparative experiment with gunpowder, gun-cotton and dynamite.

The charges (180 lbs. of powder at P, 47·3 lbs. of gun-cotton at C, and 29 7 lbs. of dynamite at D,) were placed behind a revetment wall by means of shafts and chambers, as shown in figs. 9 and 10; they were fired simultaneously by a dynamo-electric machine and all exploded. The powder did by far the most work, and, weight for weight, the dynamite did more than the cotton.

The detonator for the cotton contained 10 grammes of fulminate of mercury.

Experiment No. 22. In this experiment, 24·25 lbs. of cotton, and 24·25 lbs. of dynamite were placed respectively at A and A (fig. 12) on the sole of a loophole, with a sandbag on each charge (fig. 13), the dynamite being in a cartridge 15 c. × 12 c. × 12 c.; they were detonated simultaneously, and produced identical effects, namely, in each case blowing out the pier between the loopholes in which the charge was placed, and that to the left of it, as shown in fig. 11, by the line C D E.

Experiment No. 23. Two charges of the same weight as in No. 22, were placed on boards, supported on spikes driven in on a level with the bottoms of the loopholes, and in positions corresponding to B B, fig. 12, only in front of a fresh portion of the wall. When fired, they each destroyed the face of the pier against which they were placed, but only to a slight depth, the effect in each case being apparently the same.

The dynamite was in a cartridge 20 inches × $4\frac{1}{2}$ inches, while the cotton occupied a length of 1 foot 9 inches between the loopholes.

Comparative experiments were carried out with dynamite and gun-cotton on a pair of similar expense magazines with arched roofs and covered with earth. The particulars of the construction are shown in figs. 15 and 16.

Experiment No. 24. Charges of 8·5 lbs. of gun-cotton in one case, and of dynamite in the other, were placed at i, fig. 14, suspended beneath the arch. In each case the effect was only slightly to dent the under surface of the arch.

Experiment No. 25. Similar charges (each of 8·5 lbs.) were placed on top of the earth covering at ii, fig. 14; the result was almost nil.

Experiment No. 26. Charges of 11·5 lbs. in one case of dynamite, and in the other of gun-cotton, were placed at iii, fig. 14, on the crown of each arch, the earth having been removed for the purpose; these charges were then covered with two feet of earth, as tamping. When fired, the dynamite destroyed the arch, as shewn in figs. 14 and 15., while the gun-cotton only broke down some of the bottom rings, and did not penetrate, though it shook the rest of the masonry more than the dynamite did.

Further experiments were made with gun-cotton and dynamite on arched roofs.—The building used in this case was a powder magazine, of which sections are given in figs. 16 and 17. The earth over the crown had been removed as shown, before the experiments.

Experiment No. 27. In this case 15·4 lbs. of dynamite and the same of gun-cotton, were propped up with posts at A and B respectively (fig. 16) under the crown of the arch. These charges were fired together by electricity. The detonation caused a crack in the end wall above the small window, and each charge punched a dent in the arch of about 18 in. × 12 in. × 12 in.; the arch had also lifted at H, fig. 17, and fallen down again, the upper course of brickwork hanging a little below the lower one. On the top, a crack extended along the whole length of the crown of the arch.

Experiment No. 28. A charge of 15·4 lbs. of dynamite, with a similar one of gun-cotton, was next placed, without tamping, on the top of the crown of the arch at D and C (fig. 16) and fired. Neither charge broke through the arch, but the dynamite broke away a little of the bottom ring.

Experiment No. 29. Two grooves 0·35 metres long by 0·32 metres deep, and 0·2 metres wide, had been cut before the experiments in the crown of the arch, as shewn at E and F, (fig. 16). 13·2 lbs. of gun-cotton were placed in one, and the same amount of dynamite in the other. The charges were covered with 0·2 metres (8 ins.) of sand, and fired. They blew through the arch, forming a gap 3 metres long and 2 metres wide. Previous to this the arch had been a good deal shaken.

To demolish a brick wall, with loopholes, the following charges were used, viz. :—

Experiment No. 30. A charge of 17·3 lbs. of dynamite placed in a groove in masonry, as at A, fig. 18 and 19.

Experiment No. 31. A charge of 25·3 lbs. of dynamite placed in the earth, as at B_1, fig. 19.

Experiment No. 32. A charge of 17·3 lbs. of gun-cotton placed similary to the 1st charge.

Experiment No. 33. A charge of 25·3 lbs. of gun-cotton, placed similarly to the second charge.

All four were fired together, the results were very similar, and are shown by the chain-dotted lines, fig. 19, where the wall was blown away entirely.

If anything, Nos. 31 and 32 produced most effect. The general result of the comparison seemed to be that the dynamite is a little more powerful in its action than compressed gun-cotton, but owing to the other advantages possessed by the gun-cotton, it seemed, on the whole, to be thought more efficient than the former for military demolitions.

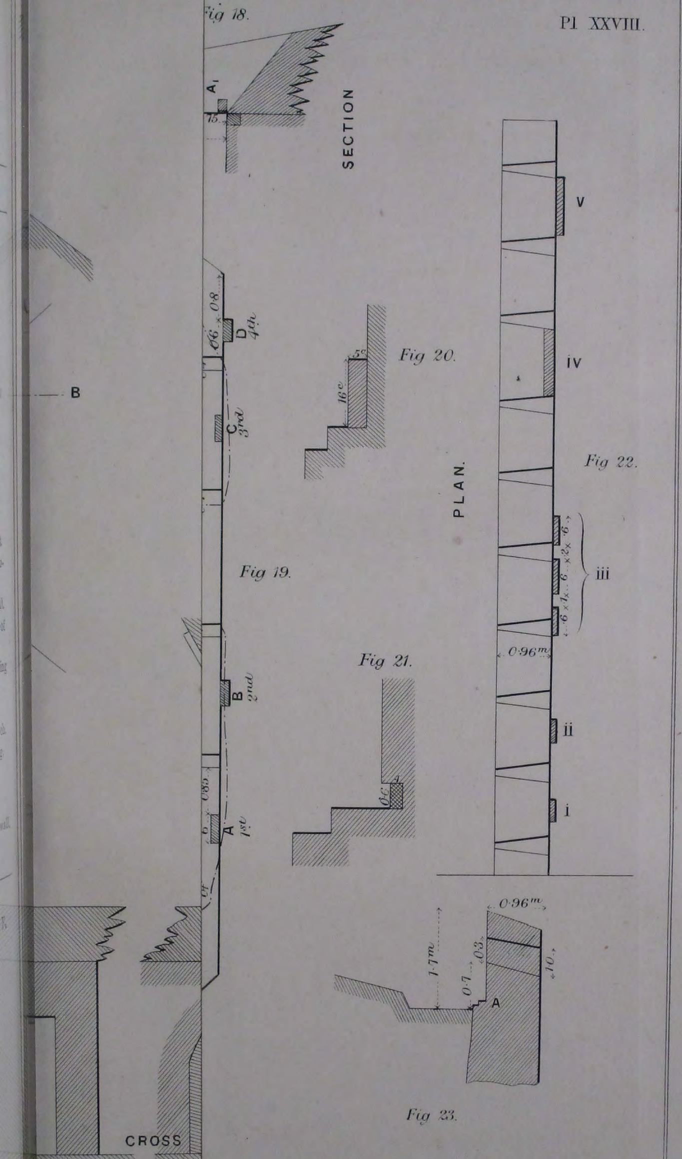
The German officers said, that even in the open air, the fumes after dynamite had been detonated were apt to be injurious.

TABLE SHOWING THE NUMBER AND THE NATURE OF THE EXPERIMENTS.

Number.	DESCRIPTION.
1	Charge of dynamite hung against a wall.
2, 3	Charges of dynamite at the foot of a wall.
4	Two charges of dynamite fired together at the foot of a wall.
5, 6	Two charges connected by piping, one intended to fire the other.
7, 8	Comparison of dynamite and powder lodged under gate piers.
9 to 14	Experiments on different forms of cartridges for dynamite.
15	Dynamite used to destroy a gate lock.
16	Untamped dynamite against masonry.
17 & 18	Tamped ditto ditto ditto.
19	Tamped dynamite (charges at intervals) against masonry.
20	Dynamite lodged in the centre of a wall.
21	Comparison of dynamite, gun-cotton, and powder, behind a revetment.
22	Comparison of dynamite and gun-cotton fired in the loop-holes of a communication.
23	Ditto ditto ditto supported (on boards) against the wall.
24	Comparison of dynamite and gun-cotton, supported under the crown of a casemated arch.
25	Comparison of dynamite and gun-cotton on top of the earth covering of the arch.
26	Ditto ditto ditto laid on the crown of the arch (tamped.)
27	Ditto ditto ditto supported under the crown of a casemate arch.
28	Ditto ditto ditto laid untamped on the crown of the arch ring.
29	Ditto ditto ditto laid tamped on ditto ditto
30, 31, 32, 33	Comparative charges of dynamite and gun-cotton against a parapet wall.

T. F.

Pl. XXVIII.



THOS KELL, LITH. 40, KING STREET, COVENT GARDEN.

PAPER XII.

DESCRIPTION OF THE OPERATION OF STRAIGHTENING THE BRICK CHIMNEY SHAFT OF THE GAS WORKS AT THE ROYAL ARSENAL, WOOLWICH.

By Lieut. Col. SCRATCHLEY, R. E., and Lieut. WATSON, R. E.

The following description of this interesting operation may prove of service, and as it can, without doubt, be applied to chimney shafts of any height, it will, in most cases, be worth a trial, before adopting the expensive course of rebuilding shafts which have become inclined.

The operation at the Arsenal was carried out under the superintendence of Lieut.-Col. Scratchley, R.E., Inspector of Works, Manufacturing Departments, and Lieut. Watson, R.E., by Mr. Ralph Hall, of 126, North Frederick Street, Glasgow, a well-known "Steeple Jack," who has had great experience in all matters relating to defective chimney shafts, the repair and refixing of their caps and lightning conductors.

The price paid for the work was £50, a very moderate sum, when it is considered that the cost of removing the old shaft and rebuilding the chimney, with a good pile foundation, was estimated at £650.

It will be seen that the operation is very simple and apparently unattended with any risk; but the operator must possess great coolness and experience.

The Arsenal shaft, which is one hundred feet high, was erected in 1860. (*Vide* Pl. XXIX)

From borings taken prior to its erection, it was found that the subsoil consisted of clay resting on a bed of peat situated at a considerable depth below the surface of the ground. With this bed of clay it was considered at the time unnecessary to have a pile foundation, and a mass of blue lias lime concrete, 30 feet square, and 8 feet thick, was provided.

Soon after the chimney was completed it was observed to be inclining from the perpendicular, and in December, 1861, it was leaning over 19 inches to the south, and $24\frac{1}{2}$ inches to the west. Observations were taken with a theodolite, and continued at intervals up to the middle of 1873, when it was found that the inclination of the chimney had increased to $33\frac{1}{2}$ inches to the south and $42\frac{1}{2}$ inches to the west The increase in the inclination was not uniform, but became more rapid between the years 1871 and 1873; consequently, although the limit of safety (72 inches of inclination) had not been reached, it was decided to attempt to straighten the chimney rather than rebuild it.

It is difficult, without a careful examination of the foundations, which would be a costly matter, to assign an exact cause for their failure; but it is quite possible that the peat may have become compressed by the weight of the chimney, estimated at about 720 tons, which caused the concrete to crack.

After consultation with Mr. Hall, it was determined to cut out the brickwork at the top of the chimney base, where its thickness is 2 feet 3 inches at the angles, and 1 foot 10½ inches at the sides, exclusive of the firebrick lining to the flue, which, as it was bulging out, had to be removed.

An old steam boiler tube was erected to serve the purpose of a temporary chimney, and a scaffold, consisting of one plank supported by poles, having been constructed round the shaft at a convenient height, Mr. Hall, assisted only by one labourer, commenced to take out two complete courses of bricks throughout the entire thickness of the chimney, commencing at the point marked *a* on plan (*vide* plate), working gradually round in the direction marked by arrows until the point *g* was reached. From *g* to *a* no bricks were removed, because when the chimney was straightened this angle of the shaft would be found to be at about the proper level.

As the bricks were taken out, two courses at a time and two bricks wide throughout, they were replaced by two other courses of bricks of varying thicknesses, set in sand, mixed with just sufficient lime to make it bind and keep it from falling out when the sawing, hereafter described, commenced.

Between the points *b* and *d* and *d* and *f* the two courses of bricks were of less thickness than those between *a* and *b* and *g* and *f*, but they were laid with a much thicker layer of sand and lime.

This part of the operation occupied Mr. Hall and his assistant about eight working days, after which the straightening of the chimney was commenced, by the very gradual removal of the layers of sand, and courses of bricks previously put in, an iron cross-cut saw, one-sixteenth of an inch thick, and provided with very coarse teeth, being used for the former; Mr. Hall working on the outside, and his assistant on the inside, of the chimney.

As the sand on the top of the upper course of bricks was removed by the saw, the shaft gradually settled down, turning on the angle *a g* as a fulcrum. The upper course of bricks was then taken out and replaced by thinner bricks or tiles set in sand or lime as before. The sawing being resumed, the sand was worked out, the tiles were again removed and replaced only by sand, and so on.

As the process was continued the shaft came over imperceptibly, until it reached a perpendicular position, when it was found that the angle *d* had fallen 5½ inches, *b* and *f* 3 inches, while *h* had risen one quarter of an inch. Observations taken with the theodolite shewed that the shaft was vertical on the south side, but inclined 4 inches on the west side, as it was impossible to make it absolutely upright in consequence of the chimney having originally gone over in a diagonal direction. The last part of the operation was to replace the remaining bricks and tiles by bricks set in cement, and cut to suit the wedge-shaped opening left in the brickwork. The work was completed in three weeks.

It is essential to ensure success that the following points be attended to:—

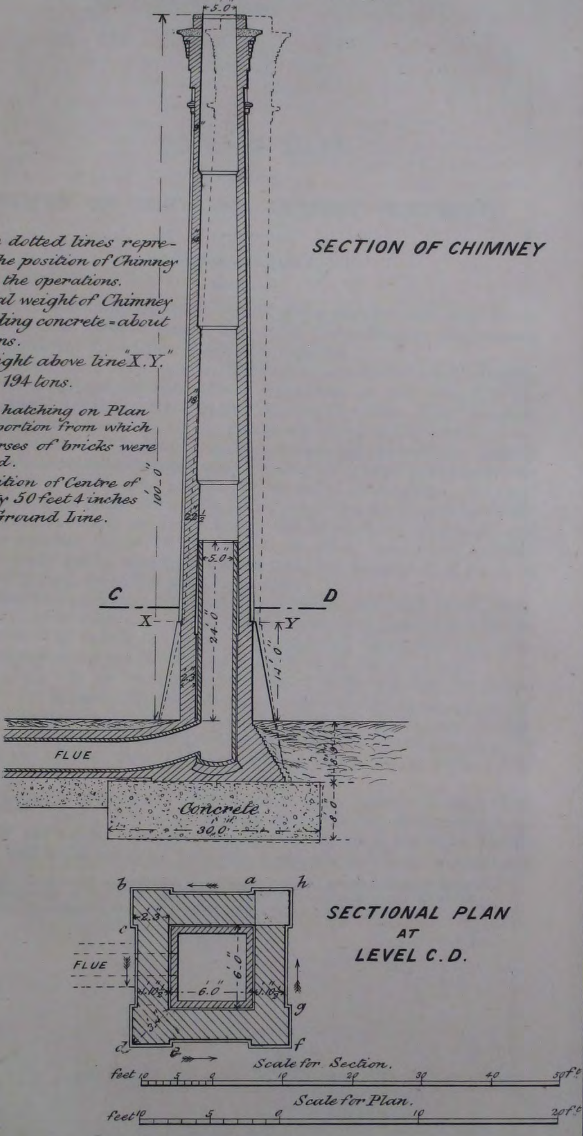
1. The sand and bricks must be very carefully packed, so as to leave as little as possible of the shaft unsupported at any time.

2. This packing of sand and bricks must be removed very gradually to prevent the shaft from returning to a perpendicular position too rapidly.

Royal Arsenal, June 8th, 1874.

P. H. S.
C.W.W.

STRAIGHTENING OF CHIMNEY
AT THE GAS WORKS
ROYAL ARSENAL WOOLWICH.



NOTES. (1.) The dotted lines represent the position of Chimney before the operations.

(2.) Total weight of Chimney including concrete = about 720 tons.

(3.) Weight above line "X.Y." = about 194 tons.

(4.) The hatching on Plan shews portion from which two courses of bricks were removed.

(5.) Position of Centre of Gravity 50 feet 4 inches from Ground Line.

PAPER XIII.

NOTES ON PORTLAND CEMENT CONCRETE.

By Major MAQUAY, R.E.

These notes are compiled with a view of giving some practical rules for the manipulation of Portland cement concrete, in the construction of permanent fortifications and the erection of habitable buildings.

The manufacture and properties of Portland cement, and the results of mixing it in various proportions with different ingredients, are fully treated in Mr. Reid's works, and also by Mr. J. Grant, C.E.; and Capt. Innes, R.E.,* has given valuable instructions for the supply, storage and testing of this cement.

The application of Portland cement concrete in the construction of parts of permanent fortifications possesses many advantages over other building materials, on account of the economy attending its use and of its durability. The rapid progress of work caused by its quick-setting properties; the ultimate hardness it attains in air or under water; the facility with which it can be prepared and laid by unskilled labour; its characteristic of setting when mixed with salt water equally well as when fresh water is used; and its property of not being affected by frost, are further points in its favour.

Cement concrete is specially suited for revetments, bombproof covers, floors, and work under water or in wet soils, and is an excellent material for habitable buildings. The economy to be gained by employing this material will, however, depend on the presence of stone or gravel on the site of the work.

Supply of the cement. In the construction of extensive works with Portland cement concrete, it is desirable to obtain the cement of an uniform quality direct from the manufacturers of the article. A specification to ensure the supply of a good cement, and the directions for receiving and testing it, are given at the end of these notes, and were enforced at the defence works in Cork Harbour.

Selection of the ingredients. In selecting the ingredients to make concrete, the chief object should be to obtain such as are suitable for admixture with the cement, and can be procured economically at the site of the works. Broken stone, hard bricks, chippings from stone-yards, gravel, ballast, and burnt clay

* "The Manufacture of Portland Cement," and "Portland Cement Concrete," by Reid.
The Papers read by Mr. Grant before the Institute of Civil Engineers in 1865 and 1871.
Captain Innes' Paper in Vol. XXI of the R.E. Corps Papers for 1873.

can all be mixed with cement, lime, and sand to make concrete; but it is necessary to study the properties of these ingredients so as to determine the proportions in which the aggregates should be mixed to secure the best results. Stones and rocks possessing an average amount of porosity are preferable to those of a harder texture or polished surface, or to such as have the character of absorbing much water; thus cement will adhere better to Kentish rag stone, Portland roach, hard bricks, and granite, than to flints, smooth gravel and pebbles, which do not give a sufficiently absorbent or rough surface for the matrix to adhere to.

Stones should be broken square with sharp edges; slatey fragments are not themselves a good ingredient. When stones and gravel are scarce but clay is abundant, the clay can be burnt in clamps at a moderate cost, and will make a good ingredient for concrete. Ballast, *i.e.*, gravel and sand mixed—as raised from the beds of rivers, if perfectly free from any loam or mud, is a good material to mix with cement to form a close and compact concrete. The sand used in making concrete should be perfectly clean, sharp, not too fine, and with no trace of earthy particles.

Proportion of ingredients.

The proportions of the aggregates forming a concrete are regulated by the nature of the ingredients, and the description of work for which it is to be used. Smooth gravel, flints, and very porous materials require to be mixed with more cement than substances of a moderately absorbent quality.

A proportion of one part of cement, by bulk, to eight parts of broken stone and sand will be found suitable for most purposes; as, for instance, for arches, piers, walls, floors, and revetments. The sand should be in the proportion of one-third of the bulk of the broken stone. In foundations and coverings over arches, a smaller quantity of cement, say from one to ten or twelve of the other ingredients, will be sufficient.

Concrete laid under water may have the proportion of cement increased to one to four or six of the other materials, to make up for what may be lost by the unavoidable scour and wash of tides or currents before the mass has set.

The quantity of matrix or cementing substances in a concrete—that is to say, the cement and sand—should be in excess of the voids in the coarser ingredient. Thus, to broken stone passing through a mesh of $1\frac{1}{2}$ in. should be added one-third its volume of sand, besides the cement in the proportion to the whole bulk, say one-eighth; these when mixed, watered, and rammed, will produce a quantity of concrete one-tenth greater than the original volume of broken stone.

The quantity of water required for mixing with the dry ingredients to form a concrete, will vary with the season of the year and the characteristics of the materials used; some judgement is therefore requisite in adding the water. The following is a good practical guide. The water added should only be sufficient to moisten the ingredients, and must not be allowed to flow over the surface of the mixing board, or to run down the sides of the heap that is being mixed, for if it does flow down, it washes away the cement and fine particles of sand from the surface of the broken stones or coarser materials, and impoverishes the concrete.

Methods of making concrete.

Concrete can be mixed by hand, or by means of steam machinery. The first method is convenient when there is ample space, materials in quantity close at hand, and cheap labour; but concrete is mixed by machinery more uniformly, rapidly, and economically, than by hand; a comparison of the cost of these two systems of mixing concrete is given at the end of these notes.

Mixing by hand.

In mixing by hand, a boarded stage or floor is required, about 8 ft. wide and 15 ft. long, and a frame for gauging or measuring the ingredients. A convenient size for this frame is a square box, open at top and bottom, of 5 ft. 6 in. sides, and 1 ft. 4 in. deep. The gauging frame is put at one end of the stage, and broken stone is shovelled into it to a depth of 12 in., and then a quantity of sand, sufficient to fill the remaining four inches; to these are added two sacks of cement, each containing two bushels (if received well filled from the manufacturer, they should contain that amount). By adopting a frame of the above dimensions, and by using two sacks to the frame full of other materials, a proportion of 1 of cement to 8 of other ingredients is obtained, and the necessity of measuring the proportion of cement is avoided. The bulk of concrete that these quantities of aggregates will produce is one-and-a-quarter yards cube.

After the ingredients have been placed in the frame, it is lifted off the heap by means of handles on the sides; the dry materials are then turned over to the other end of the stage or mixing board by two men, with square mouthed shovels, working towards each other along one side of the heap that came out of the frame. Care should be taken to make this turned over heap of the same form as the original one, for if worked up to a pile, the larger stones will roll to the foot of it. Two other men with shovels will commence at the end of the new heap, and turn over about a barrow load of the material at a time, while a third man adds the water, by means of a watering-pot fitted with a *rose*. Too much attention cannot be paid to the rose being invariably used for this operation, for if the water is poured out of a spout, hose, or bucket, it will scour away the cement from the stones and sand. After the operation of watering, the moistened barrow-load can be shovelled into wheelbarrows, or other means of transport, and is then ready for laying in the work.

Machine made Concrete.

When large quantities of concrete are required, it can be more evenly mixed and turned out at less cost by machinery than by hand. The form of mixer commonly used by contractors is driven by steam-power, and consists of a revolving hollow cylinder about 3 ft. in diameter, and 12 to 14 ft. long, set at an angle of 6 to 8 degrees to the horizon. The cylinder is usually made of hard wood lagging, lined with sheet-iron, fixed by hoop-iron bands over four cast-iron discs or wheels, keyed on a 3-inch shaft in the axis of the cylinder.

The ingredients are measured in a hopper at the upper end of this cylinder, and by its revolutions (which should be 16 to 20 per minute) they are mixed and passed out at the lower end. The objection to this long drum is, that it is difficult to regulate the quantity of water to be added, as the materials are so enclosed, that the state of moisture they are in cannot be judged by the eye.

A much better mixer is a fixed semi-cylinder of wrought or cast-iron, in the axis of which revolves a $3\frac{1}{2}$ inch square wrought iron shaft, with 3 to 4 blades each side of it, set at a pitch like a screw-propellor; these blades mix and deliver the concrete. The upper end of the mixer is closed, the lower end open, but with a cross bar to take the bearing for the shaft; the cross section of the cylinder should be more than a semi-circle, to prevent the materials being pushed over the side by the blades, and the cylinder should be set at a small angle to the horizon.

By using a double hopper at the head of a mixer of this description, the delivery of concrete will be almost constant; for while the ingredients are being measured into one hopper, the other will be feeding the mixer.

The supply of water is served and regulated by a stop-cock and iron pipe, with holes along its bottom, suspended horizontally over the upper end of the shaft and blades.

It will be found that the open mixer, with revolving shaft, delivers concrete into wheelbarrows or trucks, much better than the closed drum, and this is a considerable advantage.

Where the mixing station is distant from the work to be constructed, iron tip-trucks on a tramway can be employed to receive the concrete from the mixers, and deliver it where required.

Stone breakers.

When stone has to be broken for the concrete, one of Blake's Stone Crushers can be worked by the same steam-engine that drives the mixer, and the broken stone may be delivered direct into the feed hopper, or raised up to it by means of an endless band with buckets. (fig. 1, Pl. XXX).

Blake's Stone Breakers have produced most satisfactory results where applied to the concrete mixing stations at the Defence Works, in Cork Harbour. These machines do not get out of order, require little attention, and if constantly fed with stone, break up a large quantity in the day. Limestone and granite are crushed by these machines in a form specially well suited for concrete mixing.

Concrete mixing by Steam power.

The arrangement for the combination of a stone breaker and a mixer depends on the site. The annexed sketches are of two mixing stations that have been found to give good results.

In (fig. 1, Pl. XXX) where the site is level, and the work close to the mixing station an eight-horse power portable class of engine drives a breaker, a mixer, and an elevator; five yards of concrete an hour can be turned out by this system.

The other mixing station, (Pl. XXXI) is applicable for a site where large masses of concrete have to be laid, and where elevation can be obtained, to give a command over the work for the delivery of the concrete. In this arrangement, there is a mortar pan for mixing lime concrete, and a winding drum for raising material from a lower level.

The engine for such a mixing station should be of about 12-horse power; it will break the stone, wind up the material, and mix about eight yards of concrete an hour. The double hopper and direct delivery of broken stone into it, keep the mixer well served with material, and produce a constant supply of concrete.

Laying concrete. Concrete can be laid or moulded to any form by means of sheeting, panelling, and centering. It is essential to work in level beds, for if the concrete is laid at a slope, the water will trickle away with the cement, and leave the sand and stones almost clean. The concrete should be evenly and gently punned or rammed; and the surface of a bed on which fresh concrete is to be put must be perfectly clean and well watered, especially if the first bed has had time to set. This point requires much attention: the bed should be as rough as possible, and if it has been rammed smooth the surface must be picked up; for in the operation of ramming, the water and fine particles are pressed to the top of the bed, and with them the milky substance that is present in moistened Portland cement; if this is not removed before fresh concrete is put on, the new stuff will not adhere to the old work.

It has been found in cutting out set Portland cement concrete, that the mass if well made, is as close and hard as the best stone; but the beds or joints of different batches of concrete are always the weak parts, where they have not been carefully attended to, and these joints when defective can be opened by iron wedges or feathers just like veins in rocks.

For massive work, such as deep foundations, pier walls, abutments, and thick revetments, small boulders and lumps of stone can be thrown in by hand with the concrete; these blocks should be packed close or far apart, according to the nature of the work, care being taken to keep them away from the face. They should be clean, free from any dust or clay on the surface, and well watered before being embedded in the concrete. In foundations, two-thirds of the whole mass may be blocks of stone, and the more irregular their shape the better will the concrete adhere to them. In walls, abutments, and revetments, the stones should be put on edge and may be 3 to 4 inches apart, the concrete being tucked in between them with an iron punning tool, about 3 feet long, provided with an eye handle, and a cross head of iron, 4 inches long and $1\frac{1}{3}$ inches wide on the face, (fig. 5, Pl. XXXIII). The points of these stones should be allowed to project above the top of the beds in order to give the next layer of concrete a good hold of the old work.

The concrete should be worked with the blade of a spade or trowel along the face of the panelling or sheeting used to retain the materials, so as to bring the finer particles to the face of the work. Attention must be paid to the joints of the sheeting, to see that no moisture runs out between the planks, for any water getting away from the concrete, takes a portion of cement and sand with with it, and on removing the sheeting, cavities will be found where the joints have been left open. Some whitening and plaster of Paris mixed in equal proportions, makes a good stopping to pay over the joints and defects in the casing.

When 3-inch planks are used for sheeting, the distance apart of the struts or guides supporting them should not exceed 7 feet; above this distance planks of this thickness will spring or bulge outwards to the weight of the concrete and the pressure of ramming.

Concrete escarps. In making escarp revetments in concrete, where there is not much space on the berm for mixing the materials, a stage on truck wheels and a moveable tramway, of the design in Pl. XXXII, has been found to give great facilities for sheeting. This structure is readily put together, the material being all of 3-inch planks, and its weight, with that of the ingredients for the concrete on the mixing platforms, gives stiffness to it, and prevents any bulging of the sheeting under the process of ramming.

Concrete walls. Panelling is the most convenient form of casing for making concrete walls to retain the material in the progress of work. For large walls, as sea walls, the panels may be 4 feet deep, 14 feet long, of 3-inch rough planks, edges shot, dowelled, clamped at ends, or ledged at back; for narrow walls they may be reduced in all their dimensions, say 2 feet 6 inches deep by 12 feet long, of $1\frac{1}{2}$-inch plank, planed on face. The panels are kept together and adjusted by means of $\frac{3}{4}$-inch iron tie rods passing through them, screwed at both ends, and furnished with tapped handles; pieces of wood, the width of the wall, being inserted between the panels near their top edge, to keep them the required width apart, till the concrete is put in. The holes for the rods to pass through should be 3 to 6 inches from the edges of the panels, and as the panels are moved up they rest by the lower tie rods on the old work, and are screwed up to the faces of the wall.

Panels may be shifted 12 hours after the concrete has been put in, provided that it has not been mixed with much water. After the panels are taken down they must be thoroughly cleaned before being set up again.

Lumps of stone, or clean brick-bats, *well watered*, may be thrown in with the concrete, in size and quantity according to the thickness of the wall, as explained in a previous paragraph, thereby greatly reducing the cost of the work. When using panelling, attention must be paid to the instructions given about having the beds of each course clean, rough, and moist, to receive the next layer of concrete.

After the panels are set up for the fresh work it is well to point with very stiff cement mortar along the edges of the old bed where the panels meet it, to prevent water running down the face of the wall from the next lot of concrete. This pointing must not be done with a mortar richer in cement than the concrete, otherwise lines of a different colour to the rest of the work will appear on the lines of the beds. The face of sea walls and revetments may be left rough, as the panels leave them, if care has been taken to work well with the spade or trowel where the concrete touches the panels, so as to bring the fine stuff to the front of the work.

In thin walls requiring a more finished surface the face may be floated over with a water brush and wooden float, as soon as the panels have been removed; but no *rendering* should be allowed, as it will give a patchy appearance.

Sea Walls. Some sea walls are exposed to great attrition of boulders and shingle; in this case, Portland cement concrete does not attain sufficient hardness for a considerable time to resist this action unless the planks or panels used in the construction of the base of the wall can be left in their position for a year or more, or till the concrete has attained its greatest ultimate hardness.

If there is time to make concrete blocks for the part of the wall that the shingle rubs against, and to give several months for them to set hard, they can be used in the face of the work and backed with Portland cement concrete.

A facing of hard stone will answer the same purpose, slabs being used for stretchers (called "shiners" in the mason's trade) dovetailed into heading stones running well back into the work.

Hollow walls. Hollow walls for buildings in damp and exposed situations are easily made with concrete. Panels, like those above described, about 18 in. deep, are used for the exterior faces of the walls, the hollow space of about 3 in. wide being made by two planks 1 in. thick and 18 in. deep, with hard wood wedges and clips to keep them apart, as shewn in fig. 1, Pl. XXXIII.

Iron bonding-ties, of the pattern shewn in fig. 2, are set across the hollow space every two or three feet on each bed, the planks forming this space having in their lower edge notches that ride over the iron ties; if these are required to break bond, intermediate notches are cut in the planks. The tie-rods of the panels pass through the planks forming the hollow space. Care must be taken not to allow any concrete to drop into this space, and this can be prevented by tacking slips of wood on the upper edges of the planks between the clips and wedges.

Concrete arches. Arches in Portland cement concrete are the most satisfactory work producible with this material. They can be turned over the ordinary centering used for brick arches with close lagging, or on solid cores built up of earth and stones.

It is not necessary with concrete to adhere to the circular, or elliptical, form for arches over chambers and passages, for in spaces not exceeding ten feet width, a flat covering is more easily and economically made, and a prismoidal soffit can be given to greater spans, using the planks or panelling employed in forming the vertical walls.

In making a covering with concrete across a span, whether of the arch form or flat, it is requisite to complete to a uniform thickness a portion from springing to springing in the day's work, racking or stepping back, and leaving rough the end of the completed part to give a good tie for the concrete that is to be laid on the next day. For very thick bombproof covers, about two or three feet of the thickness of the arch should be made of a homogeneous concrete without any lumps of stone, but after that has sufficiently set, the covering may be brought to any required depth in horizontal beds, with boulders and lumps of stone, as for other massive work.

Hollow spaces over arches. It is easy with concrete to form a double or hollow arch over powder magazines, in continuation of the hollow space round the walls of the same, thereby ensuring great dryness in these chambers. (Pl. XXXIV.) After the hollow space in the side and end walls has been brought up to springing level, an arch about 9 in. thick is turned over centering, and the extrados rendered to a smooth surface; two thicknesses of wedge-shaped battens are laid on the top of the finished arch, washed over with whitening and plaster of Paris to close the joints, and the second concrete arch is made over this new centering. The battens are cut from a piece of 4½ by 3 in. scantling, sawn diagonally, to make a pair of batten wedges 2 in. thick at one end, and 1 in. thick at the other. They are laid to form the centering for the second arch, with the ends reversed, and when the concrete has set, these wedges can be driven out, and will leave a hollow space of 3 in. between the two arches. Another method is to spread 2 or 3 in. of sand over the first arch, and cover it with thin planks, to form a centering or core for the second arch. This system is more easily managed than the one with battens, the only trouble being the labour of clearing out any sand that may drop into the hollow space of the walls. To facilitate this operation, it is necessary to leave an opening at the bottom of these hollow spaces.

Arches turned on solid cores. Concrete arches, or domes, can be made over solid cores without centering or lagging; stones and earth or sand can be built up and rammed into the form of the intrados of the required arch; this is plastered over with weak mortar or stiff clay, and the concrete laid in one operation over the whole curved surface.

Building huts of concrete. Huts of concrete can be built with panels and vertical guides, securely strutted at the angles and at intervals along the walls. The panels are rebated at the ends, to slide in corresponding rebates on the edges of the guides, and are fastened by means of wood or coach screws, at the required height as shown in fig. 3, Pl. XXXIII. The tie rods, before mentioned for adjusting the panels in making walls, can be applied to regulate the position of the vertical guides.

If many huts of the same dimensions have to be erected, it will be found economical, and productive of very rapid progress, to use a cast-iron casing to retain the concrete for *the whole of the walls to their full height.* This casing may be made up of plates of convenient size, with bored flanges to receive bolts and nuts, on the principle used in the construction of cast-iron tanks.

Cases for two huts would be required, so that while the concrete is being laid into one, the casing for another hut can be put together. By this means *a whole hut can be erected in one day*, if sufficient labour and materials for the concrete are available. The door and window frames may be fixed in the openings left for them, (on a system to be described presently), either during the progress of the concreting of the hut, or after the cast-iron case has been removed.

Floors and roofs. For floors, the concrete must be mixed with as little water as possible, and be laid six to nine inches deep. The concrete should be evenly punned or rammed, with a wooden mallet to the required level, and after being allowed to set for some hours, say half a day, a wooden float should be worked over the surface to make it smooth, the mallet at the same time being used to press down any points of broken stone that may have a tendency to project above the level of the floor. If any water comes to the surface in the first operation of ramming, it must be soaked up with a dry water brush, otherwise it will percolate through the concrete before it sets, and depressions will be left in the floor ; it is for this reason that the materials should be mixed very dry. No rendering should be allowed to make up inequalities, for it will certainly scale off after the the floor has set.

Concrete floors, when well laid, give a very firm hold for the feet, and will stand a great deal of wear.

Slabs of concrete 3 in. to 4 in. thick can be substituted for stone flagging when there is time to allow the slabs to set a few months before they are required to be laid.

Roofs. Roofs for huts or sheds can be made of a layer of concrete $2\frac{1}{2}$ in. or 3 in. thick, over close sheeting, that may be left rough on the underside, or planed to serve as a ceiling that can be varnished, painted, or whitewashed, according to circumstances.

The concrete for roofs should be made of finer ingredients than that used for walls, and the surface finished off as described for making floors, but it is better for this operation to use an iron instead of a wooden float, in order to obtain a close and smooth surface for water to run off.

The weight of the concrete forming a roof must be calculated with a view to determine the thickness of the sheeting and the distance apart and dimensions of the purlins or rafters required to support it.

Roofs of huts may be made of a slightly arched form, or of sloping planes with hips and ridges ; the first is the more convenient form to adopt ; the sheeting can be supported on slight ribs, to be removed after the concrete has set.

Concrete dressings for buildings. Portland cement concrete can be cast with great facility in wooden or iron moulds to the forms adapted for cut stone dressings of window and door openings, and other parts of buildings, such as the plinth, string, and barge courses, copings and cornices. In buildings made entirely of Portland cement concrete, it is convenient to cast in this material the sills and lintels of the window and door openings, and set them as the work progresses.

A sketch (Pl. XXXV.) is given of window dressings that are applicable to a brick building with hollow walls ; they are designed with toothed quoins, to avoid a straight joint between the brickwork and the jambs, that might otherwise allow moisture to pass into the hollow space. Concrete dressings in a brick building have a very pleasing effect.

Arrises in concrete work. It is advisable to round off or chamfer all arrises or sharp edges in concrete work. This is done when the sheeting or casing to contain the concrete has been fixed, by filling up the angles with a moulding of plaster of Paris and whiting, or by tacking in fillets of wood to the form required. The former is the simpler, more expeditious, and more economical method.

Fixing door and window frames.

To provide for the renewal of door and window frames that are set in concrete, it is advisable to let into the reveals, as the work progresses, iron cramps with screwed ends, as shewn in fig. 4, Pl. XXXV. By this means new frames can be fixed when the old ones become decayed, and can be set into the work more firmly than by using wood bricks, that generally shrink away from the concrete.

Concrete laid under water.

Concrete when made with Portland cement, possesses the great characteristic of setting under water, whether fresh or salt. The chief point to attend to in laying concrete under water is to avoid any scour from tides or currents, that wash the cement out of the concrete. To effect this, the work must be protected with sheeting, and the concrete should be passed to the spot under water, where it is to rest, by means of shoots.

It is well in this description of work to mix and collect the concrete in quantities of 20 to 30 yards six hours before it is required. The proportion of cement should be increased, as before noted, to one-fourth or sixth of the other ingredients in order to accelerate the setting of the mass laid under water, and to make up for any loss of cement caused by the rise and fall of the tide through the concrete, or the wash and scour of any current between the joints of the sheeting.

A good system of casing or sheeting to retain concrete laid in water is shewn in Pl.XXX. It consists of railway iron bars of the bridge rail section and 3-inch planks. The flanges of the rails are bored with $\frac{1}{4}$-inch holes 9 inches apart to receive wood screws for fixing the planks; the rails are set up to the form required, and their lower ends secured with lumps of rich concrete, let into the rock, or sunk into the bed, according to the nature of the ground; they are adjusted by means of inch round bars, with screwed forked ends to pass through the flanges and secured with nuts, and the rails are kept apart by temporary struts of wood, or by other rails, till sufficient concrete has been laid to allow of the removal of these struts. The 3-inch planks are fixed against the flanges of the rails with coach screws, and the ends of the planks made to butt at the rail; for planks of 3-inch thickness the rails should not be more than 7 feet apart.

If there is any apprehension of a scour of water between the edges of the planks, old sails or sacks tacked on outside the sheeting will prevent any of the ingredients of the concrete being washed out.

This form of case gives an equal pressure of water on all sides in tide ways, by allowing the water to rise and fall internally where no concrete has been laid, and posseses the great advantage of dispensing with coffer dams and pumping, the most expensive part of engineering operations in this nature of work, which must be resorted to with any other material than Portland cement concrete.

The concrete should not be allowed to pass through the water in the operation of laying it, without being confined in a shoot down to the point where it is to rest. Presuming that a body of concrete of 20 or 30 yards has been collected near the site of the work, temporary barrow runs or stages are made above the highest water level between the rail uprights; at the ends of these runs, shoots, 12 in. to 18 in. square, with hopper heads, are attached in a way that will admit of their being readily moved from one spot to another, the end of the shoot being kept two to three feet from the level of the bottom of the work. The concrete is then tipped or shovelled into the hoppers and made to pass down the shoots, keeping the hopper and shoot as full as possible, and shifting them from one spot to another as the delivery at the bottom becomes choked up. By keeping the shoot full, the concrete does not come in contact with the water till it has reached the spot where it is to be left to set.

The length of the shoot having to be reduced as the work rises in layers or beds of 3 ft. or 4 ft., it should be made of inch planks, kept together with hoop iron to resist the pressure of the column of concrete; the shoot can be cut or shortened as required.

General Gillmore, in his work on limes and cements, describes an ingenious machine, consisting of a shoot with moveable flaps or stages inside that mix the concrete on its passage down the shoot, and deliver it at the base.

If the structure to be made under water is extensive, it may be convenient to use cast or wrought iron shoots, made in lengths to take off as the work rises. Stout canvas shoots with wooden hoppers will answer the same purpose, enabling the position of the delivery to be more easily shifted and guided, but they wear out quickly.

As in other massive concrete constructions, large stones and boulders may be built into work under water.

It is advisable in a tide-way to cover each day's work or bed of concrete with sails or old sacks loaded with stones, to prevent the surface of the fresh work being disturbed by the scour of rising and falling tides, or by the passage of currents over it.

General remarks.

It has been shown in the foregoing notes that the application of Portland cement concrete is very general for almost every nature of work forming part of permanent fortifications, and that great economy accompanies its use where suitable materials are procurable near the site of the works. For coast defences, therefore, this concrete can be employed with the best advantages, as the shingle, sand, and salt water forming its principal ingredients are generally on the spot.

Experiments have not been made with the special object of ascertaining whether Portland cement concrete expands or contracts to any degree in setting or from changes of temperature, but works constructed of this material both of a massive and slight nature, have been closely watched to detect any change of form or bulk, and no trace of expansion or contraction can be observed.

Portland cement concrete does not attain its ultimate maximum hardness and strength for probably two years, but after a few months it becomes sufficiently set for all practical purposes to admit of the utilization of the buildings constructed with it; this property renders concrete habitations available at an earlier period than when they are made of stone or brick and mortar, and it is of the greatest value in the construction of fortifications, for it enables revetments and bomb-proof covers to be loaded with earth almost as soon as the concrete work has been completed.

The resistance of concrete made with Portlant cement to penetration of projectiles, after it has attained its greatest strength, has not been determined, but from the effects of elongated shells that have been fired from rifled muzzle-loading guns into concrete of moderate strength, used for backing to experimental shields and targets, it has been ascertained that while the penetration is about one-third greater than in granite masonry, the disruption in the mass of concrete is less than in the masonry, there being no joints to extend the injury caused by the violence of the impact of the shot.

The superior slopes of gun emplacements made with this concrete (under the directions given for making floors) are not affected by the discharge of any nature of gunpowder over them. For these surfaces all plastering or rendering must be carefully avoided, as it is sure to scale off under the blast of heavy ordnance; the last bed of concrete should not be less than nine inches thick.

As Portland cement concrete dries of a light colour it should be discoloured when used in batteries, especially under the muzzles of guns, so as to bring all parts to the colour of grass or earth. Stockholm tar and yellow ochre mixed with paraffin oil or turpentine make a very good wash that can be toned down to imitate the earthern slopes of works.*

There is scarcely any limit to the application of Portland cement concrete for building purposes; the foregoing notes have only touched on its use in works which the military engineer is chiefly called upon to construct, but it can be applied with advantage and economy in almost all the branches of the building trade where stone is now employed. For tanks of all sizes, and drains of any form, this concrete is well suited; channel courses moulded in concrete will stand wheel traffic; traps for drains can be moulded in this material with the frames for the gratings cast in them; and it is equally applicable for making sinks, hearth stones, cornices, and mouldings of all forms.

To recapitulate the essential points for attention in the use of Portlant cement concrete:—As regards the cement and the testing process, it should be heavy and ground very fine; 110 lbs. to the bushel is a good weight. Cement lighter than this will set fast, but will not attain as great a hardness as a cement heavier than the weight quoted. The greater the fineness of the ground article the more cementing properties it will develop; all coarse particles of cement are only so much sand in the powder, for this reason the excess of 20 per cent. that will not pass a sieve of 2,500 meshes to the square inch should be rejected or deducted from the quantity received from a contractor. Should the cement contain too much chalk in its constitution, it will be detected during the operations of testing by the wet pat cracking and swelling; or if it contains more than a proper proportion of clay, it will shew itself by the dry pat shrinking and setting of a yellowish instead of a light grey colour. In either case it is

* Woodfall and Co.'s patent liquid paints are durable on concrete surfaces.

desirable to reject the cement, though its tensile strength may come up to specification.

In testing cement it would be more satisfactory to arrive at conclusions on the quality of a cement after the briquettes for ascertaining its tensile strength have had a month, or even three months, to set under water; but it would not be practicable on the generality of works to keep cement stored for so long a time before using it, and it would be difficult to find a contractor or manufacturer to submit to so long a period for a decision on the quality of his supply, and at the end of that time to be liable to have his cement rejected; for these reasons seven days' immersion in water has been adopted by most engineers as the time to take tests for tensile strength.

With regard to the other ingredients of the concrete, the broken stone, shingle, and sand, should be perfectly free from earth, clay, or dust; no more water should be added than is sufficient to moisten all the ingredients. If any blocks of stone or bricks are built into the work they must be saturated with water and their surfaces must be perfectly clean. As a rule these stones should be set on their ends. The ramming should be evenly and gently distributed over the whole work. In joining fresh concrete with that which has already set, the surface of the old work must be rough, clean, and well moistened.

Comparative cost of Portland Cement Concrete, mixed by steam machinery, and by hand labour, and the price of same at civil labour rates.

In the following schedule the cost per yard of concrete is based on the prices of the materials of which the Portland cement concrete was made at the defence works in Cork Harbour. The difficulty of access to the forts at this station enhanced the prices of all the ingredients that are quoted as follows:—

Portland cement from London manufacturers, including charges for use and return of packages, and conveyance from wharfs in the Harbour to the different forts, at per ton, 63s.

Sand from contractor, screened and washed, per yard cube, 4s. 5d.

Lime stone in lumps, for breaking or for hearting of work, per ton, 3s. 6d.

In every instance the proportion of the materials are one of Portland cement to eight of other ingredients, the sand being one-third of the broken stone; all in bulk.

Allowance is made for the cost of the sheeting, panelling, or centering used, and for fixing and removing same, and for all work on the surface of walls and arches; and where machinery is used, the cost of driving, consumption of fuel, and wear and tear of plant is accounted for.

Where boulders or hearting of large stones are built into the work, their proportion to the concrete is given, and the prices include collecting, laying, and ramming these into the work.

NATURE OF WORK.	Per Cubic Yard.		
	Military Labour.		Estimated Cost by Civil Labour.
	Mixed by Steam Power.	Mixed by Hand.	
Dock Work or Sea Walls between High and Low Water.—Concrete of shingle, with half of mass boulders collected within 100 yards of site; railway bar iron and 3-in. plank sheeting (as in Pl. XXX.)	—	9s. 4d.	12s. 10d.
Sea Walls above High Water.—Materials as above; panels and tie-rod sheeting	7s. 6d.	8s. 0d.	9s. 11d.
Moncrieff Pit Batteries.—Concrete of stone broken by machinery (fig. 1, Pl. XXX.), sand supplied by contractor, framed sheeting, straight and circular	11s. 0d.	12s. 1d.	15s. 2d.
Casemated Batteries.—Concrete in walls, with half hearting in big lumps; stone quarried near site; concrete trucked by tramway 150 yards; sand supplied by contractor (machinery as in Pl.XXX.)	8s. 4d.	9s. 8d.	12s. 9d.
Casemated Batteries.—Arches all of concrete without hearting; the materials as in last case	11s. 4d.	12s. 9d.	16s. 4d.
Dwelling Houses.—Concrete in hollow walls, surfaces worked smooth both sides, panels and framed sheeting; lime, stone, and sand at contract prices	15s. 10d.	16s. 3d.	19s. 9d.

Specification of Portland Cement Contract, Cork Harbour.

Fineness. 1.—The cement to be the best quality of strongly burned English Portland, ground fine enough for 80 per cent. to pass a sieve of 2,500 meshes per square inch. The excess of 20 per cent. which will not pass the above mesh, to be ascertained by sifting a mixed sample of not less than 25 lbs., taken from one-tenth of the packages supplied, to be deducted from the gross amount to be paid for.

Weight. 2.—The cement to weigh not less than 110 lbs. per striked bushel, when filled into the measure as lightly as possible by sliding down a piece of board or spouting.

Strength. 3.—Briquettes of net cement, gauged as stiff as possible, and put into water within 24 hours, to have a minimum tensile strength of $562\frac{1}{2}$ lbs. to 2·25 square inches of section after seven days' immersion. Tests from every tenth package must give an average up to the above, with not more than 2 per cent. of the tests below the minimum.

Dry and water tests. 4.—Sample pats about 3 inches diameter by half an inch, gauged net, and kept dry, must set well without shrinking, or change of colour or shape. Sample pats as above, kept in water, must set well without cracking or swelling. Tests from every tenth package must not give more than one per cent. of failures.

Chemical analysis. 5.—The cement may be subjected to a chemical analysis to ascertain its purity, the proportion of its ingredients, and the absence of foreign matter.

Instructions for receiving Portland Cement for Works in Cork Harbour.

1. A non-commissioned officer is to be detailed at each fort, to take charge of the Portland cement and lime stores, and his duties will be as follows :—

2. To take charge of cement and lime supplied by contractors for the works, see it unloaded from vessels, and stored where ordered by the Superintending Royal Engineer Officer, and stacked in such a manner as may be directed.

3. On a cargo of Portland cement arriving from the contractor for that material, the non-commissioned officer in charge of cement store will be informed by the Superintending Royal Engineer Officer of the number of sacks invoiced in the cargo. He will be present with the local contractor's agent when the hold of the ship is opened, and will notice the condition of the cargo, especially as to any signs of damp or water having got to the upper sacks or casks, and also the condition of those in the lower part of the hold as the cargo is unloaded. The non-commissioned officer will keep a tally of every package brought out, and record the number in a book provided for the purpose.

4. He will not allow to be loaded in the carts any damaged casks or broken sacks, or any that show signs of hard lumps in them; they will be put to one side *in the ship* till all the sound packages are unloaded, when he may employ the local contractor's men to collect any good cement, that is, cement in a state of powder, from the damaged packages, and put it into sound ones, refusing to land lumps of cement, but receiving and noting the number of casks or sacks refilled.

5. If any rain falls, unloading the vessel to be stopped and hatches closed.

6. The non-commissioned officer will make a report on each cargo, under the following heads :—

a. General condition of cargo as to dryness.

b. Number and nature of packages, whether new or old, if good and sound, and how many of them broken or damaged, and if all well secured.

c. Weight and contents of every fiftieth cask or hundredth sack, and to note if all sacks seem evenly filled, and give the weight of cement in the whole cargo, less casks or sacks, and weight per bushel.

d. Time taken to unload vessel, noting any break caused by rain.

e. Number of men employed unloading vessel and storing cement, and number of carts.

This report to be sent to the Testing Office, signed by the Superintending Officer of the station at which the cargo is delivered.

7. Portland cement cargoes to be stored separately, so that in the event of the tests to be applied to the cement proving unsatisfactory, instructions can be given for the disposal of each cargo.

Lime is supplied by local contractor at the stores. The non-commissioned officer will only have to report the quantities and condition of this material, and store it as directed.

8. The non-commissioned officer at the vessel will take samples for testing from every tenth cask or every twentieth sack, and put them in small bags provided for the purpose, to be sent to the testing office.

9.—Every fiftieth cask or hundredth sack to be weighed, and the contents noted, deducting weight of package, under the head "weight of cement per cask or sack, and weight per bushel." The bushel measure to be filled by sliding the cement gently into it down a wooden shoot or spouting, without pressing the cement or shaking the measure.

10. The casks or sacks opened for taking samples from to be carefully secured again before storing.

11. Any sacks that are unstitched will be sewn up before being returned to the contractor. The empty sacks will be made up into bales of fifty sacks in each bale, securely corded, and each package labelled and addressed.

Issuing cement.

12. Cement will be issued from store by the non-commissioned officer, on requisitions from non-commissioned officers in charge of works (signed by an officer of Royal Engineers), and he will record the issues to each part of the works in his books.

13. The return to store of casks and sacks must be specially looked after; he will report to the superintending Royal Engineer officer any deficiency in returned packages from the different parts of the works.

Testing the Cement.

1. The cement testing machine, moulds, presses, and plates to be carefully looked to, and kept clean and oiled. The sieves to be kept in a dry place where no rust can get at them, and to be brushed clean after use.

Adie's Cement Testing Machine applies a strain of 300 lbs. to 1,100 lbs., according to the position of the running weight, as indicated by the figures on the lower scale of the lever. When a greater strain is required, the extra weight applied to the notch on the upper side of the lever will increase the figures on the lower scale by 500 lbs. If a strain under 300 lbs. has to be recorded, the brass counterweight is to be hooked on to the small counter-lever at the end of the long arm, reading the strain on the upper scale.

2. A briquette to be made out of a portion of neat cement, taken from each small sample bag. In making these, the cement to be mixed on a board, with *as little water as possible*, and pressed, with the gloves provided for that purpose, into every corner of the gun-metal moulds, one of the iron plates having

been previously placed at the bottom of the mould. The briquette will be passed out of the mould as soon as possible by means of the "press," and put into the troughs. To admit of this being done quickly, the neat cement must be mixed *very* stiff. As soon as the trough is full of briquettes, water is to be poured in gently to cover them completely. The mixing board to be cleaned after each briquette is made.

3. Two circular cakes of neat cement to be made, six inches in diameter, and half-an-inch thick, with the smallest quantity of water. When they are sufficiently set to permit of their removal from the board on which they were mixed, one of them is to be put into water, and the other left in the open air. After twenty-four hours' immersion, the water cake to be carefully examined, and if there are no indications on its surface of cracks or hair-like fissures, the cement may be considered free from an excess of lime, and thoroughly hydraulic in character. The cake in the open air should be light grey in colour, but if it proves to be yellow and ochrey, the cement contains too large a proportion of clay, and will be deficient in tensile strength. If the water cake cracks, and the air cake is of a yellowish colour, the cement should be at once removed from the works.

4. The cement left in the sampling bags to be turned out in a heap and mixed up. The weight per bushel to be ascertained in the same manner as directed for non-commissioned officer receiving the cement.

5. One hundred pounds weight of the cement to be sifted through the sieve of 2,500 meshes per square inch, and the per centage of coarse particles that will not pass through the sieve to be weighed and noted. This operation to be done twice, that is, with two lots of 100 lbs. each.

6. After the briquettes have been immersed in the water troughs seven days, they will be broken down in the testing machine. The breaking weight of each briquette is to be noted and an average taken.

In breaking down each sample, the weight to be brought to the zero each time, the briquettes placed into the clips, and gentle strain put on by means of the hand wheel, till the arm rises in the guide standards. The weight will then be moved along the lever by means of the handle and ratchet wheel, with the pall down; the hand never to be applied to move the weight.

7. One of the cement testing forms to be filled in for each cargo, under the proper columns for every stage in the process of testing, and the average results noted in the book kept for the purpose. In the column for remarks, notes to be made of condition of cargo and packages, from the report of the non-commissioned officer in charge of cement stores; also the appearance of the sample pats and per centage of briquettes under the minimum tensile strength allowed by specification; date of arrival of cargo, and name of vessel and manufacturer or contractor for supply to be given. An abstract of result of tests to be sent to each station on one of the testing forms.

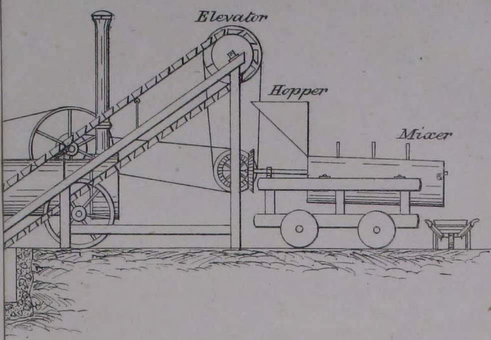
(PATTERN FORM FOR)

CEMENT TESTING REGISTER.

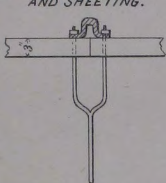
(EXAMPLE.)

No. of Tests.	Dates of			Age.			Weight in lbs.			Per centage of coarse. Sieve. 2,500 meshes per square inch.	By whom supplied, and Date.	Moulded by	Tested by	Remarks.
	Moulding.	Immersion.	Breaking.	Days in Air.	Days in Water.	Total.	Per Sack.	Per Bushel.	Breaking strain on 2·25 sq. in.					
120	1 Jan., 1874.	1 Jan., 1874.	7 Jan., 1874.	—	7	7	lbs. 228	lbs. 112	lbs. 728	lbs. 18.5	Burnham, Brick, Lime, and Cement Company. 24 Feb., 1874.	Sapper B. Gabion.	Sapper B. Gabion.	New Sacks. Per ship Result. 24 Feb., 1874. Discharged at Fort Camden.

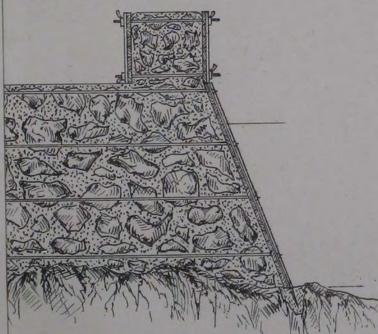
J. P. M.



DETAIL PLAN OF RAIL
AND SHEETING.



SECTION AT A.B.

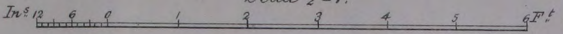


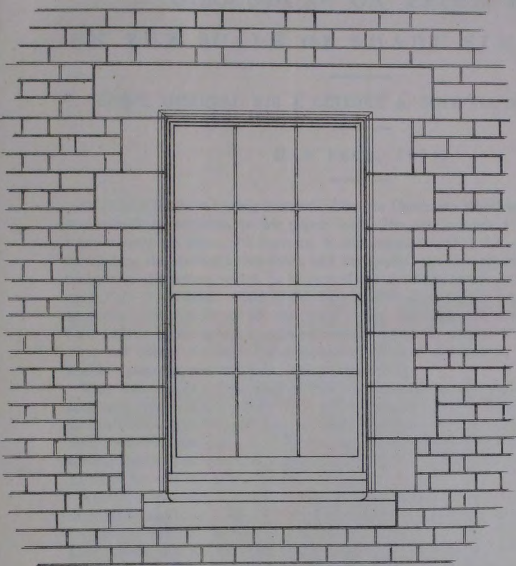
Draw
La

PL. XXXV.

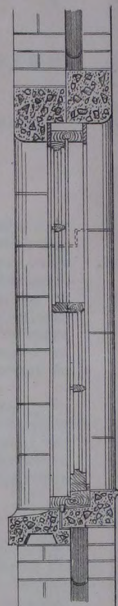
CONCRETE MOULDED JAMBS SILLS AND LINTELS ADAPTED TO A BRICK BUILDING WITH HOLLOW WALLS.

Scale $\frac{1}{2}'' = 1'$.

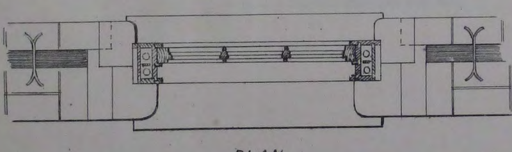




ELEVATION.



SECTION.



PLAN.

Drawn by J. Hill.
Lance Corp.l R.E.

DISCUSSION* ON PAPER VII.

ON THE SCALE OF SHADE SIMPLIFIED.

LIEUT. GENERAL SIR J. LINTORN A. SIMMONS, IN THE CHAIR.

MAY 28TH, 1874.

CAPTAIN MILLAR having been asked by the Chairman whether he wished to make any remark in addition to his paper said: The only remark I wish to add is that, since writing my paper, I have come to the conclusion that the scale is rather coarse at 20 deg., the strokes being thick and far apart. On this account I am inclined to make a modification, which is to extend the medium strokes as far as 25 deg. It makes the work finer. That is the only modification that it seems to me necessary to make. This drawing on the wall shows the different thicknesses of stroke, and, as it is drawn to scale, enlarged twenty times, the strokes must be pretty correct. It is not meant to show the ornamental effect of the system, but is intended for another purpose, which I will point out presently.

THE CHAIRMAN: The meeting will be glad to hear any observations any gentleman may desire to make with reference to this subject. It is one of great interest to us as military men, who have to describe ground by plans such that others may read them with facility. A letter has been placed in my hands from Lieut. Fawkes, stating that he has some propositions of his own to lay before the meeting, which, perhaps, he will explain in detail.

LIEUT. FAWKES: I merely wish to ask your permission to show a different method of shading. For this method any *scale of shade* is applicable, whether Captain Millar's or the one at present in use; it is merely a different method of applying the shade. The shading is put on, so that it can be transferred by the lithographer. The contours are left white instead of being shewn black, so that they become much more distinct than in the ordinary process of hâchuring. Instead of having the contours scarcely distinguishable, I show them quite white, and the darker the slopes the whiter they become. This is merely a matter of detail, and does not affect any question of *scale* of shade at all. Any *scale* can be used.

THE CHAIRMAN: I understand your idea is to leave the contours white, so that they shall not be lost to sight in putting in the hâchuring. How do you accomplish that object? Because there is a great tendency in drawing to obliterate the contours, or draw the hâchures over them. You have accomplished it in this specimen; but how do you do it actually in drawings?

* Held at the War Office, 28th May, 1874.

LIEUT. FAWKES: The method I wish to propose may be briefly described as follows:—The contours are put in lightly with a *soft* pencil. The details of fences, &c., are inked in with lithographic ink. The paper is laid upon a smooth piece of Bristol board, and the contours indented carefully with uniform pressure. The slopes are then shaded with lithographic chalk and as the chalk does not enter the indentations, the contours are left white. The woods and houses are then filled in. The sketch is transferred to stone or zinc, and as many copies taken as may be required. If copies are required, the paper must have been prepared for lithography. For this purpose a simple coating of starch is all that is necessary. I have a number of sketches here which illustrate the different styles or "touches" which may be used in shading by the method I propose. Some are lithographed; others are merely original sketches done by hand. If I am not taking up too much time, I will ask your permission to read a few extracts from the description which I have written, which will, perhaps, more thoroughly explain my proposal. "So many objections have been raised from time to time against the present methods of representing hilly ground, whether it be by brushwork in Indian ink, or by a scale of shade laboriously etched in with the pen, that it appears desirable to consider whether some other method cannot be adopted which shall produce a better effect, and be at the same time easier of execution. The following method is proposed for consideration, as fulfilling both these conditions. It is adapted either for rapidly and effectively shading a hasty sketch without contours, and, therefore, necessarily more or less inaccurate; or for applying a scale of shade carefully executed to a finished drawing, the contours in this case being left white and distinctly visible through the darkest shading. A contoured drawing thus shaded, conveys, moreover, to the uneducated eye, and to the generality of officers, a far better idea of the general character of the ground than is produced by the present system of contours and hâchures combined. It is much more easily executed than either brushwork or etching, neither of which produces at all a satisfactory result, except in the hands of a skilled draughtsman. It has also this advantage, that whereas etching is not adapted to a hasty sketch, and brushwork cannot be transferred to stone (at least, as it is usually executed), this method is superior to both, inasmuch as the sketch can be rapidly executed, and any number of copies can be taken that may be required. (If you do the etching you can take the copies, but you cannot do it quickly; and if you do the brushwork, you cannot take the copies). If the sketch is to be transferred to stone or zinc, the surface of the paper must be kept in good order; but if merely an original sketch is required, the shading should be fixed to the paper by the following means:—The sketch is laid upon a pad of several folds of perfectly smooth paper. Three or four folds of clean white blotting paper are laid upon it, and the chalk is rubbed well into the surface by means of a round smooth piece of wood (such as the bowl of a wooden pipe, which answers the purpose as well as anything), the folds of blotting paper being between the chalk and the rubber. It will be found that only a very small amount of chalk will come off on the blotting paper, even with hard rubbing. The chalk must on no account be rubbed in in this way if intended to be transferred. If the sketch is not intended to be transferred, pencil marks can be rubbed out after the contours are indented and before the shading, if they are not put in too heavily. If the sketch is to be transferred, they are unimportant, as they will not transfer; and rubbing them out will spoil the prepared surface. If dotted contours are required, the indentation is executed with the milled edge of a measuring wheel, such as is used for measuring distances along roads on a map. It is thought that the following advantages may be derived from the method of hill-sketching above described: (I) Greater facility in determining the slopes. To apply the usual scale of shade to a plan, the contours are required. In etching in the shading, the contours are either obliterated, or so far obscured as to be traced only with difficulty. In the absence of visible contours, a mistake in the shading *falsifies the slope represented*. By the proposed method the contours are not only left visibly white, but in themselves heighten the effect of the shading. The slope of the ground is ascertained at once from the *contours only;* the shading is *for effect*, and may be done either very rapidly or very carefully. In either case, a mistake (within limits) does not falsify the slope represented. (II.) Extreme rapidity of execution, if necessary (applicable to hasty reconnaissance sketches), or extreme accuracy of shading if time will allow. (III.) More satisfactory effect in the hands of a moderate or inferior draughtsman. (IV.) Facility of taking as many copies as may be required. If lithographic chalk cannot be obtained on the spot, a very fair effect can be produced with the indelible blue pencil now commonly used in offices, &c., that is, for an original sketch, not intended to be transferred."

In asking your permission to submit this proposal, I have had the following object in view. Much valuable time is taken up in teaching hâchuring, and in endeavouring to obtain such uniformity of work from several draughtsmen that their sketches may be fitted together into one large map, if required. Practically, on actual service, there would be no time for this laborious shading by hâchures. Instead of this, one draughtsman uses one hasty method, another uses another method, and, probably there are no two alike. My object is to submit a few varieties of *practical rapid shading*, any one of which may be selected to afford a basis for a uniform system of rapid shading in the field without contours; while the *same instruction* will also enable a student to produce, when he has sufficient time to devote to the purpose, an effective finished drawing, carefully shaded to any authorized scale of shade, with the contours as the basis of the scale. Then for such plans as require hâchuring, it can be left for such skilled draughtsmen as are really able to do it, and this would be a special study in itself.

MAJOR WEBBER: Captain Millar has, I think, arrived at a point in the use of the scale of shade for instructional purposes at which he has found that there has been some difficulty in teaching its use, and he has done that which I think has been felt to be necessary by all who have used it, that is, he has endeavoured to simplify it as much as possible. But I find it rather difficult to understand why he should have selected twelve strokes or twelve spaces as the number which he would adopt between his contours at the lower angles of inclination, or why he should have adopted twelve in place of eleven, or ten, or eight, or whatever other number would give a sufficiently good pictorial effect, while using a uniform number of strokes between contours. If I recollect right, Major Gen. Scott, in constructing his scale, did so more entirely with a view to pictorial effect than to anything else, and the result was that he made a scale which it was very difficult to use for purposes of instruction, because he varied the number of strokes continually between the contours at the angles of inclination into which his scale was divided. Captain Millar, in using that scale, has met with that difficulty, and, as I have said, endeavoured to simplify the scale; and I cannot help thinking, having been probably myself the first officer in this country who ever used a scale of shade for purposes of instruction, and having found the same difficulty, that the movement is in the right direction. I should like to remark that, after all, a scale of shade appears to be only a means to an end; that end being that all officers in the service who are employed for topographical purposes should, as nearly as possible, represent ground of certain slopes by lines all approximately of given thickness, and approximately at the same distance apart; and having instructed any officer or cadet in the use of the scale of shade, we hope that he would abandon it as a necessary instrument to be applied constantly to his sketch, and, in fact, having once trained the eye and hand to represent certain inclinations of ground by a certain amount of shade, he would always adhere to that, more or less, and that officers who had been taught so to use the scale would do so sufficiently for all purposes; in fact, that it would be very difficult, if not impossible, to attempt to produce absolute uniformity.

A certain number of men learn to shade by means of the scale of shade, and learn very successfully to do what they never could have done without it; but there are a certain number who can shade well whether they have a scale of shade or not. You would never be able to confine them within the absolute bounds of a scale of shade, and, therefore, it matters very little whether that scale be constructed on one plan or another. There is just one point I wish to draw from these sketches in our hands. There is a sketch of ground near Dover—one copy shaded on the scale suggested by Captain Millar, and the other by the authorized scale of shade. I have thought I might be allowed to say, with due deference to Captain Millar, that neither of these sketches represents the ground as it ought to be represented, that is, that neither scale of shade has been used as it should have been used. If either had been properly used, you would have, in each case, good representations of the ground. The defect of these sketches lies in the scale of shade not being properly used; and this leads me to remark that the scale of shade is really only the A B C of the process. I believe the real secret of teaching good shading lies, not in the use of any one scale of shade, but in one rule which can be universally applied and perfectly well understood; and that is, that in drawing what may be called sets of hâchures (and I think any one can understand the expression who has ever shaded at all) they should follow a line always and invariably which will be a line representing the steepest inclination of the slope, or, in other words, a line at right angles to the contours. It may seem a very simple rule, but if any one takes a contoured plan, and before commencing to shade, draws (especially if the contours are very intricate) a number of lines at right angles to the contours, he will find that it is not at all an easy thing to follow those lines by his sets of hâchures, and I am convinced that success in teaching will alone attend the instructor who rigidly enforces this rule from the beginning. Perhaps I have digressed slightly from the subject, but what had been impressed upon me strongly in reading some time ago this paper of Captain Millar's, and in reading over again the great many papers written a few years since on the same subject, is this, that the whole secret of teaching military sketching, as long as we are to use hâchures, lies in the simple rule I have named, and that if you teach men to shade in any other manner you will only succeed with the men who are natural artists.

If you take the drawings of Major Petley and Major Gore, men who produced good pictorial effect in horizontal hâchuring better than any others in this country, you will find that they in no way followed that rule, that the rule which I have described does not seem to have been understood by them; the success of their drawings lay in the beauty of their touch, in spite of their neglect of it. Not appreciating its importance, they never succeeded in making sketchers of any of their pupils except those who drew well naturally. If you put a pencil into the hands of a man with no beauty of touch, and if you give him that rule, he will make a drawing which expresses the ground a good deal better than the drawings of Major Petley and Major Gore. The adoption of that rule in its entirety is the sole key to success, irrespective of the kind of scale of shade you use, and that it did succeed some years ago in making a wonderful improvement in the results at the Royal Military Academy, many in this room are witnesses. I hope the meeting will excuse me saying so much upon this subject. I cannot help thinking it is a very important point; that in the endeavour to alter scales of shade, or make new ones, we may be running after that which will never improve us, whereas I feel fully convinced that following out in our schools of instruction the rule which I have described (and I ask any one to try it, and he will see how important it is) we shall place in the hands of our cadets and officers a means, without which they otherwise can never shade; and I may add that, although it is nominally recognized by many instructors, my inspection of a great number of sketches lately turned out at the various institutions, clearly tells me that it is rarely enforced, and that numbers go through their course of instruction without an evidence of its knowledge in their practice, and thus acquire a vicious system, which is the true source of their difficulties, and not the scale of shade, to the use of which so much odium is sometimes attached.

MAJOR MARSH: There are several points I should like to speak about with reference to this paper. The one that strikes me most forcibly is that which has occurred to Major Webber, and I am very glad he has mentioned it, because I do not want to appear to be too critical upon the paper, but rather to deal with the general subject. But to any one who will look carefully at the two sketches illustrating the systems, it certainly appears that there is not much advantage in the one over the other. Major Webber cannot have meant to say that he was the first officer who instructed in the scale of shade, but rather that he was the first officer who taught the use of a scale of shade at our colleges, for Major Gen. Scott was instructing the junior officers of Engineers at Chatham three years at least before Major Webber took up the scale of shade. The position we are in to-night is that of discussing whether there are sufficient grounds for changing that which now exists. I maintain that there is nothing in this paper to warrant the least ground for change. I believe myself that Lieut. Fawkes is touching the ground upon which we want to get, namely, rapidity of execution. All the work we can do in the field will depend upon the rapidity with which it is done. We are evidently working over very much more extended ground in the field than has previously been the case, and there is certainly impending a considerable change in the scales to be used. They will be smaller scales, and therefore we must be prepared to sketch over much greater areas. Any system that we introduce and maintain must have that for its object. As I understand it the ground Captain Millar takes is mainly an educational one, and I will speak rather upon that point. I do not think that the question can be fairly viewed, unless we take the legitimate object of our teaching, and that I take to be much more to train officers for *coup d'œil* in the field, and to rightly estimate the value of ground with reference to the various military purposes for which it may be used than any question of drawing. I have tried to get military applications of sketching, and I find myself invariably brought back to this point that all sketching in the field, all working with instruments in the field, is distinctly subordinate to reconnoitring; that the best reconnoitring has been done and will continue to be done without sketching, but that where a man has sufficient power to sketch, he will then be in a position to give much more reliable data to his commanding officer. That is really the point at which we are aiming. Major Webber spoke of the way in which Major Gen. Scott arrived at his scale of shade, and as I went down to assist him at Chatham in 1861, I know exactly what he did. He had then been teaching something like ten or twelve years, and examining at all the colleges. He was very intimate with Major Petley, and had a great knowledge of drawing. In order to get the scale of shade, he made the most careful comparison of all the best hill sketches he could find. He had the best assistance from Major Petley and others, and he took sketch after sketch, analysed it and discussed it with every body who would discuss it with him; and the result was a scale of shade which was an artistic gradation from the steep slopes as very dark, down to the light slopes which were very fine. There were one or two difficulties that continually kept coming up. One was that, given the ordinary ground that we find in alluvial soils the slopes are light, and that then a gradation of scale which gives a very dark tone to the high slopes of 20° and over, fails very much upon the lower ground; and although the slopes of 5° or 15° are very important for manœuvring slopes, yet the scale of shade fails a great deal for those slopes. The old style of sketching was to give a side light to such hills, and thereby get a very fine effect; but there was great difficulty in combining very steep ground with the flatter slopes. This had to be fairly met by Major Gen. Scott, and he has done it, as you are aware, with the scale which has been adopted. Another difficulty was that which we have continually heard since, which is, that there is a difficulty in certain limited formations of ground in determining which is the top of a hill and which is the bottom. This continually occurs in the present scale of shade; and if you look at the examples before you, you will find it easy to imagine that the bottom of the hill is the top of the hill. He tried all sorts of things to obviate that—whether it could be done with a slight shade of Indian ink, or a blue line, or arrow, as of the direction of water at the bottoms of the valleys. I do not think he succeeded, but it was felt that it was rather a question that arose in small portions of ground than a fault of the principle; and that when ground was more extended, and the sketches were carried out over larger areas, there would be no difficulty in ascertaining the top of the hills. Major Gen. Scott was in that position when the question was raised—and, happily for us, with great energy and earnestness—by Major Webber three or four years afterwards; and Major Webber adopted the scale of shade at the Academy, and got very good results from the Cadets. The scale of shade originally adopted by Major Gen. Scott, which was a little more tedious, was modified to meet Major Webber to a certain extent, and the result was the scale of shade we now use. To turn to the point mooted by Captain Millar in proposing to change the scale of shade, he gives us two examples. He proposes to introduce into the scale of shade at 20° a widening out of the thicker strokes.

CAPTAIN MILLAR: May I ask you to take one of the later drawings that I have had lithographed, because there are considerable errors in the earlier one?

MAJOR MARSH: One thing is very striking. The thick strokes continuing in the same thickness at 20 deg. are widened out to give an interval of, I think, double the thickness. I maintain, that any body looking at that scale of shade as it stands there, will see that it is not a properly gradated scale—that there is no alteration in the slope; and the gradation of tint ought to be true all through, so that the thick stroke at the top should gradually get thinner to the thinnest line, and that the white interval should gradually get larger. I merely put that as the artistic view of it. I do not think any of the hill sketchers on the Ordnance Survey, or any man who is going in for artistic work, would admit such a break of gradation as that should be introduced. Therefore, I maintain that Captain Millar is bound to show a very good reason indeed for introducing it, and that such a break in the artistic effect of the drawing at 20 deg., will quite spoil the tinting of the drawing. We work the scale of shade to brush work as closely as we can, taking the scale of shade as a gradated tint, and we work with the brush as close to it as possible, shading from the top at the deep tint, right down until it fines out into white paper at the bottom. Therefore, there is no way in which we could possibly introduce brush shading to agree with our pen and ink shading, if we had such a scale as that suggested by Captain Millar. I notice in Captain Millar's example, where I find 20 deg. of slope, he does not apply that scale exactly, but he has his strokes half as close again. I think he ought to explain that. Then he gives six reasons for preferring his scale which he will allow me to discuss. The first claims a considerable saving of time for the new scale ; but I find on the drawings that are submitted there are 271 hâchures cropping out at the margin of the drawing in his scale, as against 229 cropping out upon the authorised scale, which gives an additional number of strokes of 42, or 16 per cent., that is equivalent to one in six. Captain Millar claims a considerable saving of time, because there is no necessity to keep applying the scale of shade to the contours. I do not see that. I feel confident there is not that considerable saving of time, nor do I see why, in the scale of shade he proposes, one is emancipated from using the scale of shade with the contours. Then the second point, " the difficulty of making eight different strokes removed by the number being reduced to three." Of course I cannot say anything about that. If we really had to make eight with the care that they are supposed to be made with, perhaps it would be better to make three. Then his third reason is, " whatever difference of appearance there may be between drawings executed by the old and new scales of shade is to the advantage of the latter." There, again, I must demur to the example that Captain Millar submits to us. I think there is a want of success in the application of the scale of shade, and a drawing has been done by the kindness of Lieut. Everett which is on the table, and which I am sure will interest officers to see, which has the scale of shade very rigorously applied and carefully checked. It is not at all the same drawing as the other, and I do not think it fails in effect.

CAPTAIN MILLAR : Two drawings ought to have been made, one on my scale and one on the authorised scale. The lithograph does not give the same effect as the drawing.

MAJOR MARSH : Then it is bad lithographing. The fourth reason is, " The slopes are easier to distinguish, as the thin strokes, where they appear, shew at once that the slope is under ten degrees." It is a great point as to how far we can go in dividing the ground into different slopes. If we could, by any means, get zones of colour or shading to show the manœuvring slopes, say 30° when impracticable for cavalry, and 15° when impracticable for wheel carriages, there would be considerable grounds for leaving the artistic question alone, and going into some bold representation of ground which would be sufficient for the general officer. There is some difficulty in it, because directly you alter the slope which is continually occurring, there is a difficulty how to shew the lower slopes, or how to show the slopes slightly higher, so that we should be continually running the zone of colour or tinting further than it was warranted ; and when we keep in mind that a great deal of this work will be done by young officers, one feels strongly that the object should be to give as close a representation of the slopes as we can, and leave it to the higher officers to deal with military questions dependent thereon. Therefore I do not think we have at all got to the point of distinguishing very special slopes beyond the attracting of the eye and attention by the gradation we shew on our plan, and leaving men to look at the contours. I do not think we have got to the point where we shall be able to shew the ground very closely by the pictorial effect. Then in the fifth advantage claimed it is stated, that in teaching it is a great advantage to be able to attach a definite meaning to the hâchures. I do not think that is an important point. It certainly applies equally to Major Gen. Scott's scale. The thickness of Major Gen. Scott's chief stroke is the same as that proposed by Captain Millar—and therefore the same value attaches to these hâchures. In the same way all the finer strokes of Major Gen. Scott's apply to the lower slopes of the ground to 10°, and so on; therefore equal value is to be attached to the slopes on either scale. "6th. The new scale of shade can be easily drawn in a few minutes, without micrometric measurement." That I do not think is of value. I think the point we shall get to, is the one that has been touched upon by Major Webber, that each man will be so exercised in the scale of shade, when he takes an interest in it, that he will not require to work much by scale in the field. But I hope we shall get further than this, and shall have our work done by non-commissioned officers and men in a regular topographical office. I think the attention of the meeting may be invited to the fact, that we are not really further on, as regards actual work done in the field, than we were in the days of the Staff Corps and the Peninsula. The actual work done in the field now, is merely defining the lines of water-sheds and water-courses, with the roads, villages, and woods. We have not got any further as regards shewing the slopes of ground. We contend, as touching military sketching, that we are able to shew the slopes of the ground so as to affect the disposition of the troops, and to give the commanding officer sufficient data on which to form his dispositions, but I do not think we have done it at present. There are many officers now instructed in the use of the instruments that have been employed for the last 40 years, but the outcome, with the exception of considerable rude reconnaissance and so on, is exactly what it was in those days. The reconnaisances that now stand in Macaulay and in Jackson's book, which was written between 1830 and 1840, are our examples of reconnoitring. We do believe that officers can go into the field and shew the gradations by the use of clinometers sufficiently to inform the commanding officer in time for action; but we have to prove it. Therefore, the question really for us to work at is, how to get the contours upon the paper—how to shew the contours. There is a great deal of misapprehension about that. When Major Gen. Scott started the contour system he did it quite independently of scale of shade. Contours had been making their way up for many years in the estimation of the corps, and the scale of shade was quite irrespective of that. Jackson, when he wrote his book, states distinctly that both himself and Mr. Burr, teaching at Sandhurst, felt the want of some scale of shade that should give uniformity to the results of sketching in the field; but it was quite independent of the question of contours; and there is no doubt a good scale of shade is independent of contours; but what we expect to get from contours is, that knowledge of ground, that accuracy in estimating slopes, which shall make an artillery officer right about his ranges, his distances, his gradients along the hill-sides for his horses and reserve ammunition. Those are the points we chiefly hope to get; and we do look upon sketching as, to a certain degree, subordinate to contours. I believe, myself, that until we can establish the fact, either by the military manœuvres, or in some practical way, that such can be done, we shall not attain that position which the subject merits. I should be very glad if some officers who know what has been doing in Germany will give us some information on the subject.

COLONEL FARRELL: I think, sir, we are all very much indebted to Captain Millar for introducing this subject. The short point seems to be that greater simplicity is desired in the scale of shade. We have a scale of shade which has been introduced after very great consideration, and has been worked at for some years. The point now is whether greater simplicity can be attained. One of Captain Millar's propositions is, that instead of so many thicknesses of stroke, as Major Gen. Scott shows in his scale, you should only have three thicknesses of stroke. Now, since that was put before us, many of us have considered the point, and I think that there is a great deal in it. It might very possibly not only simplify our work, but add to its accuracy. If this be well applied, it would be a good principle, attention being paid, first of all, to the shading of the manœuvring slopes; that is to say, if we change the scale at all, let us consider that portion of it that refers to the manœuvring slopes from 2 deg. upwards, as far as 10 deg. Beyond that, I fear Captain Millar's scale is not at all calculated to give us any facilities. On the contrary, I am afraid that what was easy in our scale originally, will be made much more difficult here. I quite agree, too, with what Major Marsh has said about the want of gradation of shade. As we have it in the authorized scale of shade we go down with a regular or palpable gradation from 35 deg. to 2 deg. The same objection was made by Captain Fothergill some few weeks ago. In looking over this scale, his expression was that there was a "want of rhythm about it." There certainly is a very great failing in this scale on that point; and, although one fault has been mentioned by Major Marsh, as occurring at the 20 deg., I think there is still more objection to be made to the extraordinary similarity of appearance between 8 deg. and 18 deg. If the gentlemen here will kindly look at these two scales together, 8 deg. and 18 deg., they will see that there is no perceptible difference excepting the slightest possible thickening of the stroke. Is that a possible distinction to be made in the hands of the reconnoitring officer? He may take the very best pen he can get, and he cannot possibly produce that difference. Where we find great certainty in our work is in the "*intervals*," for if we take up the scale of shade and wish to shade slopes, we are pretty safe as long as we have interval to guide us. For instance, I can put you down 2 deg. with perfect accuracy from memory, and so going on (as Major Gen. Scott laid it down) I reduce that interval. That is the first thing to consider in working the scale of shade. You begin with a known interval, and reduce that interval. Now you see that these 8 deg. and 18 deg. differ not at all in interval; and as to the thickness of stroke, Captain Millar says in his pamphlet that that is a most difficult thing—that greasy paper, bad ink, bad pens all combine to defeat it. I may mention that on one occasion I was anxious to make a most perfect drawing to scale of shade, and, therefore, I thought of cutting up a "scale of shade," and actually dovetailing its pieces into a sheet of paper, to form a commencement of a very accurate drawing of hills. I consequently got Messrs. Elliott to print me these scales on *thin* paper, but I found when I had them, that they did not come off the copper-plate on thin paper the same as they do on card-board. I mean to say that the texture of the paper itself will interfere with the thickness of the stroke. Thus, here in Captain Millar's type, we observe very fair work—fine lines on fine paper; now, if this were printed on different paper, the 8 deg. would appear exactly the same as the 18 deg. I must say that this is to my mind the chief objection to this scale. It does not run up, reducing your interval little by little, and it has this great fault that 8 deg. and 18 deg. are so similar. It is important, in order to realise Major Gen. Scott's idea, that we should go back to what he wrote. In his paper on the "Representation of Ground," R.E. Corps Papers, Vol. XII, you will see, after considering the whole subject, he puts very plainly before us how to teach, and since the Council of Military Education adopted his scale, I have endeavoured to teach exactly as he laid it down, and I find it is a perfectly simple method. He says, "I start with a certain shade on gentle slopes," as you may see in that drawing (pointing to a diagram hung up by Captain Millar). There is a gentle slope facing us, but the strokes laid on that gentle slope, where carried round to the two flanks, cannot by any possibility be worked in on the steeper slopes within the narrowed intervals of contours – there are twelve or fifteen of them—you cannot get them in when you come to the narrowed space. Therefore, (says Major Gen. Scott) *thicken your stroke:* let a thick stroke be considered as an agglomeration of several other strokes. That is his principle. It is NOT that you should carry down the same number of strokes all round to the opposite side. He laid down a certain principle, and I have been surprised to find in teaching his scale of shade that other persons should have attempted to carry round the same number of strokes, because it is exactly opposed to his original idea. We find we can then go on very easily. We put in the gentle slopes first—we have a certain scale for that—and then we gradually reduce the interval until interval fails us. When interval fails us, we thicken the stroke, and we go on thickening up to 25 deg. On mature consideration of both these scales, I think that it might very possibly be of advantage to adopt Captain Millar's suggestion in this way—to thicken the stroke in three different orders, and to thicken it a little earlier than Major Gen. Scott's scale does. Major Gen. Scott himself said to me after his scale had been in use for two or three years, that he thought it failed a little in richness of effect; that, at all events, in our ground at Sandhurst it did not come out as rich as he expected it would. The fact was, it was quite impossible to tie down Major Petley and other excellent artists to exactly the stroke wanted, and, therefore, he considered that as a matter of fact it would be a little better if it were a little richer. It may be made richer in two ways. All drawing is done by contrast. You could attenuate slightly the 2 deg. and thicken slightly the 10 deg. I think that point of the 2 deg. was taken up between Major Gen. Scott and Major Webber, and we find by experience we might very justly do something further in that direction, viz., make the 2 deg. more open. Some of my best draughtsmen, very carefully shading 2 deg., have filled up the valleys too heavily. If you fill up the valleys too much, you lose the effect of contrast. That is a great mistake. So that if the scale is to be altered, I should suggest, by all means, keep first to Major Gen. Scott's principles as he has laid them down, and simply enrich his scale—enrich it at 10 deg., add a type for 8 deg., do away with the 3 deg., and loosen out, or shade more lightly your 2 deg. Perhaps you might adopt for 2 deg. the type proposed by Captain Millar, which seems to be very good indeed. That is all I wish to say about the scale, but I should like to touch upon one or two other points. We ought first of all to consider the manœuvring slopes, and I think I may here say, as regards the work done in the field, it is very desirable (as has been stated already by other speakers) that the reconnoitring officer's work should be principally considered. We find pencil work saves much time in the field, and helps towards uniformity and harmony. There is greater freedom. Extra touches for marking peculiarity of ground can be more easily put in with the pencil. The one object Major Gen. Scott had in view was not to make a very perfect drawing which nobody could pick to pieces, but that officers should acquire uniformity. That was his object. I must, with Major Marsh's leave, refer to what he said as to our not being farther on at the present day than we were in the Staff Corps time. We do believe, having worked strenuously on Major Gen. Scott's system, that we are slightly further. We can set half a dozen or more officers at work at the same time on an extended position, each to sketch a separate portion, and at the close of the day their general sketches are joined together. It is assumed that this is a step in advance, and a step in the right direction, for in modern times armies cover a vastly extended position. We believe we are considerably further on, not only than we were at the time of the Staff Corps, but even than at the time when we last met round this table talking about Major Gen. Scott's proposals. Following his plan, we can take out 6 or 16 men and set them to work together with very satisfactory results ; at least, he has said so himself. With regard to the Prussians, I had an opportunity of showing some of our sketches to General Blumenthal, who expressed himself very strongly as to the excellence of the system, and took away one of Major Gen. Scott's scales of shade in his pocket. I shall be very glad to show you some sketches to bear out what I have said. I shall be very glad indeed if this discussion leads to some greater similarity in our methods of *teaching* the use of a *scale of shade.* The greatest difficulty I have is when officers come to me who have been instructed in various methods of using the scale, and when they will persist in trying to put in the same number of hâchures all the way round. When Captain Millar speaks of the great value and importance of these *hâchures* —not contours—I rather doubt it. I go very strongly for the value of the *contour*, and the contour should be figured ; but as to attaching different "meanings"—numerical values – to these hâchures, say 3 ft. or 4 ft. each, I think it would only tend to embarrass the draughtsman. As regards contouring in the field, we ought all to take up the system as much as possible. We ought all to be trained to contour, and we ought to find it very much easier than I did in my day at the Academy. We have now many new and simple instruments. It is impossible that a staff officer can find time to contour his ground for ordinary sketching. I use the aneroid constantly—consult it two or three times a day—and am quite certain that it is absurd to suppose you can run contours by an aneroid. Consider its small fine graduation. Take out your watch and just consider what the space occupied by a "minute" is. On an aneroid (common size) you have a still smaller space to divide into five by the eye. If you have good enough sight to do that, you may make out 10 feet of difference in altitudes. I carry a magnifying glass in my ordinary pocket knife, but even with this assistance the differential readings of an aneroid are difficult. The instrument, no doubt, never fails to be affected by differences of altitude, but the *reading* thereof is very difficult. Other considerations force themselves upon our notice. I once went into Messrs. Elliott's shop to test an aneroid. They had one of Major Hutchinson's pattern placed near the shop door. I said, "I will test this ; I will go down into the cellar and see what the difference is." I went down to the cellar ; took an observation there, and also one in the shop, and made out that there was a difference of about 12 ft. 6 in. between the two floors. I hit it off, as it happened, pretty correctly, and shewed the result to Mr. Elliott, who said it was very satisfactory. But five or ten minutes afterwards, on repeating the process, I made the height just half as much. I said, "How is that ?" "Oh," he said, "that is due to the effect of the draught of the door on the instrument." Now you must remember that there are currents of air ; the atmosphere is not all perfectly still. Currents of air will affect the aneroid promiscuously, if I may use the term, and, of course, we all know the effect of diurnal variation, and so on. I am perfectly convinced it is futile to do "*contouring*" in this way, and every engineer will see that anything that tends to rob the contour system of extreme accuracy should be put aside; because when we have contours figured, we want to stand by them, and not let them be upset, and to have to say, "Oh, this is put down at fifty feet, but it may be five and forty or forty." We should have our contours, if figured, trustworthy; and I do not think a staff officer has time to contour his work. I always teach every one contouring, as a basis of hill sketching, in the first year of his instruction, and he does nothing without contours; but after that, contours are thrown aside in the production of extempore rapid sketches.

MAJOR MARSH: I did not intend to underrate the work now doing in instruction, when I spoke of the Staff Corps. I meant that in Abyssinia, in China and India, and wherever we have been engaged, there has been no other kind of military sketching that is better than the work done in the Peninsula, and by the Staff Corps, and that we have to improve our position. The proof of our present system of education has yet to come. I believe there is most excellent work going on with the contour system, which will find its proper position in future campaigns.

COLONEL HAMLEY: So much that I had to say has been anticipated, that I have hardly anything left to offer. With regard to the present scale of shade, I have seen so much valuable work produced by its aid, that I should like to bear my testimony in its favour, without, however, arguing that it is not susceptible of further improvement. We have, as Colonel Farrell mentioned, amongst every batch sent to the Staff College, some officers who are absolutely destitute of skill in drawing, who have never practised topographical art at all, and yet in the course of the instruction there, they become capable of producing a representation of ground sufficiently accurate to be of great value to an officer who might be required to conduct military operations upon it; and moreover, as he has explained to you, when several officers of different degrees of skill are employed on the same piece of ground side by side, and their work is put together, it not only forms a coherent whole, but it would require some nice examination to detect any discrepancies in the work. This being the case, perhaps you will say hardly anything further is to be expected or desired in a scale of shade. However, these results are the product of a great deal of labour and expenditure of time, especially on the part of the unskilled officers, and I think any modification which would simplify the present scale would be very valuable and important. It appears to me that the right direction in which to seek this modification is in reducing the number of varieties in the thickness of stroke, which Capt. Millar has sought to do; but I think that he has not sufficiently provided for producing a striking effect on the eye, which is a great point in these rough and ready shetches. I observe he has only one thickness of stroke from 8 degrees downwards. I should prefer taking Major Gen. Scott's scale as it is, but whereas he has, between 15 degrees and 2 degrees, placed five different thicknesses, I would propose to have only three, and to produce the other gradations by means of intervals, which, as Colonel Farrell has pointed out, are much more easily preserved than the proper thickness of stroke. I think if in this way we could get an equally effective drawing, it could be done with much more ease to the draughtsman; there would be much less tax on his memory, his power of hand, and his materials. I think the present scale might stand throughout, with the exception, as I have said, that the five thicknesses should be reduced to three; and I should prefer to see all attempt to represent slope in field sketching (though not in more deliberate and permanent work), cease at 15 degs., after which one uniform thickness of line might represent all slopes, which, being equally impracticable for military movements, need not be discriminated. It is with great diffidence that I offer these observations to such an audience as this. I am sorry Major Gen. Scott is not here to-night to defend his own scale, and I am the more emboldened to suggest the modification of it because I believe his own opinion, after considerable experience of its results, tends in the direction of the alteration that I have suggested.

COLONEL MIDDLETON : Colonel Hamley has just said that he spoke with diffidence after the experts who have been addressing us ; you may fancy, therefore, that I feel even more diffidence than he did ; at the same time, as General Napier sent Captain Millar's scheme to me and directed me to ascertain the views of the different garrison instructors upon it, and report on it myself, I may as well just tell you what were the results of my enquiries, especially as I am pleased to find that they agree almost in every particular with the arguments that have been brought forward to-night. Three of those garrison instructors were in favour of the scheme altogether, two of them half in favour, and the others were opposed to it ; the principal cause of opposition being the one which has been dilated on by all the speakers this evening, the want of regular gradations throughout in the thickness of, and the spaces between, the strokes. I may also add, with regard to what Major Webber said, that every garrison instructor has almost invariably strongly impressed upon me, word for word, exactly what Major Webber has stated regarding hâchuring. My own opinion is that the scale of shade, as it now stands, is a sort of *bête noir* of the British army. The youngsters are frightened out of their lives at it, and, therefore, anything that could make it more simple would be hailed with welcome throughout the whole service. It appears to me that we lose sight of one fact, which is, that we do not want the whole of the officers of the army to be made perfect military draughtsmen ; and, moreover, if we did want them to be so, we should not succeed in obtaining our wish. The scale of shade, as it is, might be kept for the Staff College, or for the Engineers or the Artillery, the scientific corps, but a simpler plan would be of great advantage for general use in the army, so that on looking at the sketch a general officer could decide at once whether the ground was fit for manœuvring purposes. One of my garrison instructors in Edinburgh has drawn out two or three plans on the principle of making the strokes the same thickness for certain slopes. He adopted three thicknesses of strokes, which he borrowed from Captain Millar, describing one thickness as impracticable for infantry, the other just practicable, and the third "fit for manœuvring." This is, perhaps, a crude idea, which could be improved upon ; and, I think, if any plan could be found which would simplify the present scale of shade—if not for the use of the Staff College and scientific corps, at any rate, for the use of the rest of the army—it would be a very great advantage. I am very much convinced of one thing, that however well a man may know the scale of shade, if he were sent to-morrow to reconnoitre on active service his sketch would not be drawn according to the scale of shade, particularly if he had a few Uhlans hovering about in the distance. It would probably be a very rough affair, like one of the old smudges which you will find upstairs here, on which the Duke of Wellington based some of his most important movements in the Peninsular War.

MAJOR ANDERSON : So much has been said, that I can hardly add anything to it, but I may perhaps mention on behalf of the instructors in Military Topography at the Royal Military College, that with regard to Captain Millar's scale of shade, we find the same objections in the leap which he has made from 20 to 18 degrees, to which other officers have alluded this evening ; and also, as Colonel Farrell has pointed out, the similarity between the shade for 8 degrees and 18 degrees. I have before me Major Gen. Scott's scale of shade. I believe it is not his original scale, for I think I am right in saying that he altered it, after first introducing it, to make it somewhat more rich. If I recollect rightly, Major Petley found the results rather poor, and Major Gen. Scott altered it to what it is at present. Major Gen. Scott's scale is certainly more evenly graduated, and more pleasing to the eye than Captain Millar's. With regard to the scale of shade, there can be no doubt uniformity has been produced by it, and not only uniformity, but also truth. I have a sketch in my possession which I did at Sandhurst, when a boy of 17. It is a sketch of a part of the ground round Sandhurst, and for the life of you you could not make out that it was any part of it at all—I mean so far as the hâchures are concerned. I was taught by Mr. Burr to survey, and by Major Petley to draw, and this survey got me a prize ; but it is as unlike the formation of the hills as anything possibly can be. It was a very pretty style of drawing, but there was no truth in it. With regard to the importance of hâchures, I candidly confess that I sometimes regret their existence very much. Many of our cadets and students have never attained to anything like an ordinary hâchure drawing, and though they have produced a very good survey in contours, when they attempt hâchuring, the whole thing becomes utterly unintelligible. In certain hands it would be perfectly useless, though where it could be used well, a drawing can be made a very pretty thing by means of it ; but hâchures are certainly of very secondary importance to contours. Major Webber stated the only true way of drawing the hâchures was to draw them at right angles to the orthogonal lines, that is, the axis of each row of hâchures must be at right angles to the contours. It is a rule to which we adhere most rigidly at the Royal Military College. I am sure that anything (as Colonel Hamley and Colonel Middleton have said) which would simplify the scale of shade, would be a great benefit to the army. It certainly is a *bète noir* to most students, but at the same time by its means we can produce uniformity and truth, and the scale of shade ought, therefore, never to be abandoned.

CAPTAIN FOTHERGILL : I may, perhaps, be allowed to say one word with regard to a scale of shade. A good deal of misapprehension exists as to what may be obtained from a shaded drawing, and more has been expected from the scale of shade than was ever intended by its author. Anyone who has been accustomed to instruction must know how unsatisfactory are the results that are obtained by shade, and how, out of a number of draughtsmen, you get a very small per centage to produce a drawing from which you could at all judge of the slopes by the scale of shade ; in fact, I think the result of experience is that you cannot judge slopes by hâchures with any degree of truth. Therefore, the question is, how far shading should be used at all where contours can be obtained ? But as there are many cases where shading must be used, it should of course be taught according to a scale, and the present scale might be improved by cutting off at least one of the upper slopes, a slope which is scarcely ever found in nature, namely 35 deg.—indeed, the next one is of very rare occurrence—and then giving the shade for that slope to the slope of 25 deg., and fining out the light shade for 2 deg. You then have a greater difference between the two extremes of shade, and so it will be more easy to read the differences of ground as shown on the sketch. The object of a shaded drawing should be chiefly pictorial, and wherever contours can be obtained these give quite as good, and, in the case of most draughtsmen, a much better idea of ground than when they are filled in with shade. As Major Marsh observed, we have not yet attained the results we are looking for in the way of surveying, and it would very much improve the art if we had one uniform way of teaching it. At present we differ at Sandhurst—I am talking of the way of obtaining contours—from the method they have at Woolwich. Those who are accustomed to surveying by contours must know that even in the comparatively rapid way of obtaining them with the clinometer, the business is a slow one, and it is out of the question to sketch rapidly a large extent of ground if you attempt anything like accuracy in the contours. There is a method that we have lately tried at Sandhurst, which seems to be a very good one for rapid sketching, namely to make use of contours with regard only to one of their purposes. Contours of course give the height, slope, and the shape of hills. If you wish them to show the height and slope they must be at equal vertical intervals and very carefully obtained; but with regard to their shewing shape only, they need not be at equal vertical intervals, and you can commence them anywhere; neither need they be continuous. You use the contour simply to mark out the shape of the hills, for that is a thing that must be done by some guiding lines or other. This is the quickest method that one can use for sketching a large extent of ground. I merely wish to add one word with regard to shading sketches. It would be a good thing if only those who could shade well were allowed to shade them. We often have a contoured sketch brought in which is fairly intelligible, but when the shading is put upon it, it becomes simply unintelligible.

LIEUT. EVERETT: I must say I feel rather nervous in addressing an assembly composed of officers who have had so much more experience than myself. I shall not attempt, therefore, to give my views upon topographical drawing, but shall keep entirely to the point of the scale now suggested by Captain Millar. I think the three thicknesses of stroke which he proposes would in practice be found almost impracticable. Passing from one slope to another, from 10 deg. say to 5 deg., you get a gradation between those slopes, and you must employ some line of another thickness to represent the gradation. You will find if you do not adopt some other line in passing from one slope to another you get a stiffness, as may be seen in shading the slopes of a parapet, and I think, if you look at the sketch that Captain Millar has shown us on his own scale, you will find that instead of three, there are even four or five different thicknesses. I do not think it is possible to shade a piece of ground, so as fairly to represent it, without introducing lines of more thicknesses than three. Captain Millar has said that his scale is more forcible than the present scale of shade. I must say I do not think so. I have drawn here a section, the plan of which is shaded on both systems with the two shades, one by our own scale and one by that suggested by Captain Millar. No name is put to either of the scales, and I would ask anybody to tell me which is the more powerful shading of the two, the upper or the lower.

CAPTAIN MILLAR: I should like to say, besides the question of more power, there is the contrast between the light and the dark.

COLONEL HAMLEY: I certainly think the upper is the more powerful.

LIEUT. EVERETT: The upper is Major Gen. Scott's scale, and the lower that suggested by Captain Millar.

CAPTAIN MILLAR: You cannot judge by a mere scale, without taking a drawing and doing a small piece of shading.

LIEUT. EVERETT: I have taken one gradation, from 25 deg. to 5 deg., a gradation that would constantly occur in practice. If we had contours above and below the different slopes in the diagram upon the screen, the want of power would be much more visible, and we should also see that in passing from a steep slope into one far less steep, additional lines must be used. You could not put a very thin line immediately against a very thick one to show that you are passing from a slope of 25 deg. to a slope of 5 deg., because such a style of shading would mean that the change of slope was abrupt, and this abruptness does not occur in nature. You must introduce more lines. Three would not be sufficient; and if it is admitted that five or six lines are necessary, we come to Major Gen. Scott's scale. I have been for four years teaching at the Academy, and I must say I find very little difficulty in teaching the scale of shade. I have taught it to men of different attainments; some men who could not draw at all have turned out very fair draughtsmen, using the present scale. I think Captain Millar gives too much prominence to shading, as it seems to me the shade is not meant so much to give us the slope when we have the contour underneath. We examine the contour if we wish to ascertain the slope. The shade is intended to bring out the peculiarity of the ground, and I do not think shade ought to have more prominence given to it than to show the peculiarity of the ground. It adds to the appearance of the drawing, but the contour alone is really quite sufficient. I should like to call attention to the two slopes of 20 deg. and 18 deg. in the new scale. If you cover all the other slopes and place these two, of 20 deg. and 18 deg., at a sufficient distance from the eye, you will find that the 18 deg. is as dark as the 20 deg., or almost darker. This arises from the interval that is left between. Looking close, the 20 deg. appears the darkest, but at a distance of two or three yards, when you can no longer individualize the lines, the 18 deg. appear a darker shade than the 20 deg. That, I think, is a most objectionable feature of the proposal. I wish to apologise to Captain Millar for presenting a sketch which must compare favourably with one lithographed. If I had seen his pamphlet sooner, I should have been glad to have made it more fair by doing what he has also done, but I only received his pamphlet yesterday, and drew the sketch now shewn to day.

MAJOR PRATT: There is one point that has not been raised at all, and that is, that when the number of hâchures was fixed by the scale of shade, it was taken as though it indicated a fair slope. I do not think there is any principle whatever involved in the number of strokes in a slope. The actual value of the scale of shade I take to be that it introduced a system of working contours by horizontal equivalents, and that the one scale was made, giving fifty feet contours for a six inch scale, and it was so made that this scale would do for every other scale; therefore I do not think it is a matter of much importance whether there were two or four or six hâchures between any two contours. But I do think it a matter of importance that when some 3,000 officers have been taught to hâchure in one way, you should suddenly change that way for the sake of those who are coming after them,—that those who have been instructed, should change their touch and hand to another kind of shading. With reference to finding altitudes by aneroids going across the country, I quite agree that if you take an aneroid in your hand, and try and walk up and down a hill till the instrument settles at a contour, you are apt to be very far out. We have tried the new aneroids now made, and we find, by using two aneroids, one reading the number of feet above the datum from which you started, and the other being read at a fixed station, if the instrument out in the field is corrected for the fluctuation of the day, or the current referred to by a previous speaker, the aneroid will give you a good section across country. I have taken them myself over eight or ten miles, and have found nearly every station to come within two feet to four feet of the Ordnance Survey Bench Marks, and that difference is as close as you can read on the instrument. Therefore I think the aneroid will still be used in large sketching operations, although you cannot use it for contouring.

LIEUT. GENERAL NAPIER : I am exceedingly obliged to the officers of the Royal Engineers for having given me the opportunity of being present this evening to hear this subject (which, of course, is exceedingly important to me in my position) discussed so thoroughly by officers who have devoted such attention to it, and have had so much experience in teaching, particularly as it is a matter which will eventually in a great measure depend upon me for solution. As far as I am able to form an opinion upon it, I think that even Major Gen. Scott himself would be favourable to some modification of his scale. When Captain Millar first sent me his pamphlet, I forwarded it to Major Gen. Scott, who wrote to me in reply, saying he thought there was something in it, and that it might be a point for consideration whether the scale should be simplified. Although Captain Millar's modification might not be the right one, I am sure we are indebted to Captain Millar for bringing his plan forward, and so making a first attempt ; and although his scale may not be altogether an improvement on the old scale, I think, judging from what I have this evening heard, and from a report which I only got a few hours ago from Colonel Middleton, that there may possibly be an advantage, as Colonel Hamley and others have said, in making a modification in Major Gen. Scott's scale of shade. Of course it is a subject that will require further consideration.

CAPTAIN MILLAR : There have been such a variety of opinions expressed to-night, and, I may say, so many matters introduced, which are, perhaps, a little irrelevant to the exact project that I brought forward, that it is rather difficult for me to notice all the objections, which, I must say, are very numerous. First as to Lieut. Fawkes's method. I may say that it has nothing to do with my proposal; it is a separate subject of itself, on which I am sorry there were not more remarks, but the reason no doubt is, that it is a thing we cannot understand just at first. It seems to me his method, as compared with what I have brought forward to-night, is very similar to the brush system, as compared with the hâchuring system. His system is a sort of brush system, only it is done with a chalk pencil instead of by the brush. I can only say the effect it produces is certainly very good, and it gives the advantage of showing the contours much more clearly than they generally appear in hâchured plans. Then Major Webber inquired why I used twelve strokes in the lower slopes. The reason twelve is chosen is this—that it is a number divisible by four ; because I want to reduce it to six, or half the number, when the slopes get steeper, and then again to three. If you adopt eight strokes, they would be reduced to two, which would be too few, so that it is very evident why twelve strokes are chosen. I may mention it has been pointed out to me that at Chatham a system has been introduced of shading in this way. They put eight minor contours between the large contours, and carry them right round. The system is very similar to mine, only instead of trying to get eight contours in here, I reduce the number to half, and make them twice as thick. I am told they have obtained very good results at Chatham by that method. Mine is really only a modification of it.

MAJOR WEBBER: At Chatham, the greatest amount ever put is four between 25 feet contours.

CAPTAIN MILLAR : Just the same with mine ; eight between 50 feet contours is the same thing. Major Webber also pointed out the great difficulty of teaching the present scale of shade on account of the changes of thickness, and in that I quite agree with him, and that is one reason why I have brought this forward. He says that the scale of shade, when a man has been thoroughly instructed, ought to be given up, and that a good draughtsman should not be confined by a scale of shade. That may or may not be, but what I wish to bring forward is the usefulness of this system in the elementary part, when a man knows scarcely what a contour is, and has no knowledge of shading; you want something definite to place before him. Then this principle about the sets of hâchures following the steepest slopes I have no doubt is a very valuable rule, but, of course, it has nothing to do with our subject to-night. Major Marsh brought forward a point which has been several times mentioned, that the sketches produced here do not fairly represent the two systems. That, I think, is very likely. I had these sketches lithographed, and I was not at all satisfied with the way in which they were done. I had them done over again, but there was not time to keep continually correcting, and I was obliged to produce them as I could. I should be very glad if some good draughtsman would make a drawing upon my system, for then you would see its advantages; but to compare a drawing made by a first rate draughtsman with this lithograph is not fair. The main objection brought against this scheme is want of gradation. There certainly appears, in looking at the scale, a very sudden change from 20 deg. to 18 deg., and some officers say that the shading at 18 deg. does not look any darker than the 8 deg. The lithographed drawings may not be very accurate, but if you look at this drawing on the wall, in which the strokes are made to scale, you see at once, this stroke being twice the thickness of that, no one can mistake which are the thick strokes and which are the thin; and wherever you see the change from the thick to the medium, you know at that point the slope is 20 deg. In the same manner, when you see the change from the medium to the thin, you know at that particular point the slope is 10 deg.; so that you can read the slopes with some accuracy. Major Marsh says there is a loss of time, because I have 16 per cent. more strokes in my drawing than there are in the scale of shade drawing; but that is a very rough way to look at it. I might make 16 per cent. more strokes, and yet do it in half the time, if it were easier to make them, if I had not to be continually applying to a guide to get the thickness of strokes and the distance between the strokes. Major Marsh thinks it is not worth while to attempt to show gradients at all upon a sketch, I suppose because he thinks it cannot be done; but I think I have shown pretty well by this drawing, that you ought to be able to show gradients to a certain extent, because the difference in the thickness of stroke is such that you will perceive it at once. Then, again, there is nothing to prevent me making these fine strokes very much lighter, and so getting a great amount of contrast between the dark and the light. Of course I am not able to measure the strokes in the lithographed drawings, and I therefore do not vouch for them at all. It was stated, I think, by Colonel Farrell, that at the Staff College after the first year's instruction, which goes on by contours, he throws contours to the winds, and that then everything is done by the eye. I should just like to know if you have to teach men in four months any sort of hill sketching (and they have a great many other subjects also to learn in four months) how you are to treat them? You cannot spend a year in contouring; in that case, therefore, you must have something of a simple kind for them. Colonel Hamley states that Major Gen. Scott's scale has been very successful as far as teaching is concerned, but it does not provide for pictorial effect. I quite agree that Major Gen. Scott's scale is excellent, with perhaps, cadets, where it is their interest to work, and they can be compelled to work, but when you get older officers who are not so easily led, and will not be tied down to minute study in the same way, it is difficult. For myself, I like Major Gen. Scott's scale well enough to use, but to teach it is a different thing. Colonel Middleton says the scale of shade is the bugbear of young officers. I dare say to some young officers it is, but others I have found very fond of using the scale of shade and hâchuring. A great many really get to like it and take great pleasure in it ; others, on the contrary do not—it depends a good deal on whether they have sufficient patience to work at it or not. Major Anderson says that uniformity and truth are produced by the scale of shade. That I agree with to a certain extent. When there is no scale of shade used, there is great liability to error. In shading round a hill and joining at the two ends, I generally find a great many of my pupils lose about half the amount of shade they ought to have. They drop a stroke here and there ; they find it troublesome to make thick strokes, and gradually get thinner and thinner. I think my system would obviate that, because you must have the number of strokes, and having only three thicknesses, you would not be so liable to lose thickness. As to sketching of late years, I quite agree that there has been a great improvement. If any one looks at the drawings in Colonel Hamley's first edition of his well known work, he will find the sketching of the ground very unintelligible, being copied probably from old sketches done in the Peninsula. I do not think you will find such inaccuracies in the sketches of the present day. I have to thank Lieut. Gen. Napier and Colonel Hamley for speaking so favourably of some of the merits of my scale of shade, notwithstanding the many objections which have been brought against it, and I am only sorry that more officers have not taken a favourable view of it.

THE CHAIRMAN : Gentlemen, I think we are greatly indebted to Captain Millar for having given us the paper which has raised this discussion. It is a paper of considerable merit, and shows that great attention has been given by him to the mode of teaching the officers who pass under his instruction. I think we are greatly indebted to him for giving us the benefit of his experience, and for the discussion which has arisen on Major Gen. Scott's scale of shade, with a view to its improvement. Another most satisfactory point connected with the present discussion is the general expression of opinion that Major Gen. Scott's scale of shade has been of the greatest possible benefit to the service. Several thousand officers, as was stated in the course of the evening, having probably by this time been instructed in its use, it will not do rashly or hastily to make any variation from it. When I first went to Chatham as Director of that Establishment, in 1865, I found they were teaching upon one system there, upon another at Woolwich, and upon a third at Sandhurst, whilst there was a fourth in operation at the Ordnance Survey Department. I made a representation upon the subject, and, I believe, although Major Gen. Scott had long before that introduced his system at Chatham, that it was mainly upon that representation that the decision was come to by the Field Marshal Commanding-in-Chief, on the recommendation of the Council of Education, to adopt Major Gen. Scott's scale for the whole service ; it is, I conceive, absolutely necessary that we should have uniformity, and as long as a uniform system is laid down by regulation, it is incumbent upon all instructors to follow it. The scale of shade has been described by my friend here as a bugbear to young officers, but I think this is scarcely an argument against it. My firm conviction is that drill in many cases is equally a bugbear, and there is scarcely anything you can put young officers to, requiring very steady attention for several hours a day, that many of them will not pronounce to be a bugbear. That is my experience of young officers. There is another point to which I scarcely think sufficient attention is given, namely, that although you may teach all officers, it is utterly impossible to expect to make them all sketchers of ground. By grinding at cadets for days and days, you get a certain amount of fair work out of them, but you can never expect officers to devote a similar amount of attention to this work. I think it would be lamentable, because officers will not apply steadily and persistently to what may be called voluntary work, and because you cannot teach them in four months, with two or three hours' work daily, to sketch ground, that, therefore, we should abandon a scale of shade which is good in itself. We should rather keep that good scale and bring as many up to its use as possible, and not give up a good thing merely because the great mass find difficulty and have not sufficient persistence to master it. It would be better to adopt some more simple method with a more free use of written notes for officers who cannot apply the scale of shade. This is a point of very great importance, because there is a wish on the part of some to make things easy, and reduce the standard to what will suit the capacities of all, a thing which is impossible ; some can never acquire the power of sketching. My experience at Woolwich is that of the number of young men who pass through the Academy, by far the greater proportion become very fair sketchers of ground, and very good manipulators of the scale of shade—certainly more than one half—and of the rest a great proportion are very fair manipulators of it, whilst a few can do nothing at all with it. I think it would be a great misfortune to throw up good work of that sort merely because others cannot or will not devote the same amount of labour to it, or have no natural capacity for it. At the same time, I quite agree that if something can be done to simplify the scale and its application in the field, much benefit will accrue to the service ; for this reason I have been very glad of this opportunity of seeing the proposal made by Lieut. Fawkes. I do not know how far it could be applied in the field, but I think it very desirable that it should be discussed at some future meeting ; for which purpose it would, of course, be necessary that the system should be well explained beforehand, and examples of it circulated more generally than they have been, when probably some officers would try it The scale of shade will always fail to a certain extent in its application in the field. The basis of all good sketching must be the accurate delineation of the ground by contours. Now, in the field you have not always time to sketch the actual contours, but if an officer has been educated by practice in describing and sketching contours, his eye becomes educated to the work as a soldier's does to judging distances, and he will see how the contours run on the ground, and be able to sketch them with far greater facility than if he had not been trained in the first instance by actual sketching of real contours. The contour being the basis of the work, it appears to me that without abolishing the scale, we want some quicker way of shading—which after all is only a guide or help to the eye in reading a plan—than hâchuring as applied with a pen, and it is very desirable that this should be done without obliterating the contours. I dare say Lieut. Everett, who is one of the most accomplished draughtsmen I know, would tell us how many hours he has been about this little sketch.

LIEUT. EVERETT : Seven or eight.

THE CHAIRMAN : And that is quick work.

LIEUT. EVERETT : No ; very slow.

THE CHAIRMAN : I call it quick work, considering how beautifully it has been executed, but unfortunately it does not quite represent a square mile of ground. This is much more time than could be given to such a sketch on service, and I venture to think that hâchuring with a pen, although necessary for some descriptions of work, is almost inapplicable in the field. You must come to something of this sort, either brush shading or shading as in Lieut. Fawkes's sketches, which have been executed very beautifully with a crayon. This does not do away with the necessity of a scale of shade; this crayon work must equally be based upon a scale of shade, although it affords a more rapid means of producing the pictorial effect than the actual hâchuring with a pen. Having made these observations, I have only to ask you to pass a vote of thanks to Captain Millar for the paper with which he has favoured us; and at the same time I wish to express my thanks, and the thanks of my brother officers, to those officers who do not belong to the Corps, for having done us the honour to attend this meeting. We, as a Corps of Engineers, do not presume to assume to ourselves the position of teaching the army, or of placing before them what is absolutely best. We place before them our ideas, and are only too glad that they should be well discussed and considered by our brother officers in the other branches of the Service, the object of all being to improve, and to see that plan adopted which shall be best for the Service at large.

THE END.

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