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PREFACE.

The Editor desires to express his regret for the delay that has occurred in the issue of Volume XXII. of the *Occasional Papers* for 1896. The cause of the delay is as follows :—An officer had written a paper for the present volume on a subject on which he had also written a book to be published by a London firm. The maps for this volume and for the book were the same, and the whole of them were printed by the R.E. Institute printers, Messrs. W. & J. Mackay & Co. But when the present volume was on the point of being issued the London firm of publishers objected to the issue of the paper concerned until the book was first issued. This book has not appeared yet, and so, with much regret, the Editor, after some delay, has had to issue the present volume without the valuable and interesting paper referred to. It will, however, appear in the next volume.

There are three papers devoted to various means that have been actually put into practice for the passage of rivers. Lieut. W. A. Watts-Jones writes on *Flat-bottomed Boats* used on some Indian rivers; Captain J. E. Capper has written some *Notes on Suspension Bridges on the road from Kashmir to Gilgit;* while the third paper consists of the official reports *On Bridging Operations with the Chitral Relief Force in* 1895, which naturally form a very valuable record.

The remaining papers consist of one by Vice-Admiral P. H. Colomb, on *Combined Naval and Military Expeditions*, in which he points out the changes that have occurred in the conditions of naval warfare, and the effect that these changes have caused on maritime expeditions and descents on hostile shores. Mr. W. V. Herbert's lecture on *The Defence of Plevna* is full of interest, as giving the impressions and advice of one who was not only present throughout the whole of the memorable fighting around Plevna, but who also took an active part in it as a combatant officer, first as a lieutenant, and later as a captain, of a Turkish infantry battalion. The paper entitled *The Forces made Use of in War and their Proper Application* was a lecture delivered before the Irish Military Society.

The concluding paper, entitled *Notes on Indents for Pipes and other Stores for Waterworks*, had been drawn up by Major D. C. Courtney, and has been here published by the kind permission of the Secretary of State for India. This paper contains much valuable information for those engaged on waterworks.

C. B. MAYNE, MAJOR, R.E.,
Secretary, R.E. Institute.

CHATHAM,
1*st March,* 1897.

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PAPER I.

COMBINED NAVAL AND MILITARY EXPEDITIONS.

BY VICE-ADMIRAL P. H. COLOMB.

THE course of naval and military history shows, what reason and the nature of things would suggest, that naval and military expeditions carried out over sea require certain settled conditions for their success. These conditions embrace, in the first instance, the consideration of the difference between a military flying column and an army with communications and a base. The discussion of the subject, especially before a Royal Engineer audience, ought to have a sort of reflex action. If we arrive at distinct conclusions as to the conditions which must be present before we ourselves can undertake, or perhaps even consider, combined naval and military operations, we at the same time see what sort of a defensible position we hold, in view of like operations against ourselves. Seeing clearly from the defensive, as well as from the offensive side, we shall know how far we are open to such attacks, and what preparations it behoves us to make in the way of defence. And evidently the question of defence must run into two branches. If we can destroy the conditions under which such expeditions can be contemplated, we are no doubt employing "the higher policy of defence." We use a certain, and a complete method. If, however, we cannot destroy the conditions under which alone joint naval and military expeditions can be successfully conducted against us, we must fall back on a lower policy of defence, a policy which is never certain in its results, because it is subject to the chapter of accidents; and, being in the form of a repellant rather than a preventive force, it may be overcome by the concentration upon it of a more powerful attacking force.

There is a fundamental difference between warfare at sea and warfare on land, which must be carefully borne in mind in considering these questions. When an army seeks an army on land with hostile intentions, neither force can escape from the inconvenient necessities of communications and a base. But when a fleet seeks a fleet at sea, each forms a flying column, quite independent, and absolutely untrammelled by any thought of communications. Writers at the present day who take up the discussion of questions of naval strategy, but are not themselves sailors, habitually lose sight of the distinction, and habitually speak of the operations of a fleet against a fleet as if they were determined by the accessibility of a base.

The idea is an entire fallacy, due to confusion of thought. No doubt, of course, but that a fleet cannot maintain itself for an indefinite time at sea without a renewal of its supplies. Naval history is replete with instances where failure of supplies has hindered the operation of fleet against fleet. But these renewals of supply do not, and need not, proceed in a continuous stream. The fleet extending its search for the other fleet will meet its supplies at preconcerted points, and will renew itself suddenly, so as to be ready for further extending its operations as a flying column. It is the merest fancy that the question of repairs after a battle will put any limit on the radius of action of one fleet seeking another. Water supply was the chief limiting agent in the cruises of a fleet seeking another fleet in the days of sailing warships; it is now coal supply. But the alteration of the substance does not alter the bearing of supply on the nature of a fleet seeking another fleet as a flying column.

The operations of ships against an enemy's shore may be conducted, on a small scale, by means of a flying column without communications. I think the conditions required are just such as allow a small military flying column to penetrate for a short distance into an enemy's country, to destroy a bridge or surprise a work, and to return to the base in all haste. I have in my mind the instance of Hill's dash from the Portuguese frontier in May, 1812, to destroy the bridge of Almarez, and the works which protected it; a service which was completely and rapidly successful, and was carried out by a flying column, liable to be surrounded and captured by the enemy either on the outward march, or the return.

Although the clear examples of these sudden raids upon an enemy's territory over a sea which is not commanded by the power making the raid are few and far between, yet no doubt they can be made, provided the scale is very small, and the time required is short and well chosen. The governing conditions of a naval expedition of this sort seem to me entirely on all fours with those which surround a military expedition. Both forces must be limited in scale, or the enemy gets wind of it, and makes preparations to prevent its success. Both require great speed, as they have to strike and return before an adequate force can be assembled to meet them; and both demand a choice of time when the enemy may be supposed to be at least prepared.

A combined naval and military expedition may itself be a flying column, and may be conducted on a considerable scale; but then I think the conditions necessary are almost strictly analogous to those which permit of the march of a military flying column on a great scale. Wellington's army, on its last march from Portugal, was in the nature of a flying column. It parted with its Lisbon base to take up a new one in the Northern Spanish Ports. Sherman's army was a flying column, parting with its western base to take up a new one on the Atlantic shores, which the Federal navy held.

So a combined naval and military expedition may proceed from one friendly shore, across an enemy's sea to land on another friendly shore, entirely as a flying column, and without any thought of communications.

This was what was done by the Chinese combined naval and military expedition, sailing from Ta-lien-hwan Bay with a fleet and small army, to land the latter in the Yalu Estuary. I dare say you might have noticed a good deal of assertion, by way of comment on this landing, that it was an invasion. The incorrect idea may be combatted by using the analogies of the British Army in the Peninsula and the Federal Army in the Confederate States.

These analogies put the French "invasions" of Ireland at the close of last century and opening of this one into their proper category. The expeditions were none of them "invasions," in the correct sense of the term. Invasions of territory over sea do not differ in their conditions from marches over the frontier of your own continental country with that of the enemy. The French made all their attempts upon Ireland, and even the landing of the Convict Brigade on the coast of Pembroke, in the belief that they were transferring forces from one friendly country to another, just as it was in the case of the landing in the Yalu. In the case of the landing of General Humbert in Killala Bay, this basis of the operation was very marked, and no one had more occasion to speak, or spoke more freely, of the egregious blunder that his countrymen and he had made. It was supposed that Humbert's troops would land on friendly soil, and that the operation would be, in fact, over when they were landed. It was supposed that, being landed on a friendly soil, there was no need of communications, and that a succession of unconnected landings might be made in this way until the friendly soil could hold its own against all attacks upon it by the hostile English. But, as we remember, Humbert found himself landed in a country which demanded everything from him, and offered nothing in return; which was only friendly as far as he could force it to be so, and which finally swallowed him up, body and bones. The supports which were to follow Humbert in the friendly country, and which, because it was in theory friendly, did not require that the force landed should have communications, were in the first instance driven back into their ports out of the British country—the sea; and were in the second, captured or destroyed in the same enemy's territory—the sea.

In a sense, again, Napoleon's expedition to Egypt was of this character, or had, at least, this excuse for its inception. Napoleon and his countrymen supposed that the Egyptians were and would be friendly, and that Egypt might become a base for operations carried out through another friendly territory in India by land forces invading the enemy's territory over a land frontier.

In the West Indies the instances are numerous of this mere transfer of land forces, both by the French and the English, from one friendly shore to another over a sea which was not commanded; and we can see, in the history of warfare there, how an exact classification somewhat fails us, because, from operations of transfer from one absolutely friendly territory to another absolutely friendly, we run through transfers to territory which was but partially friendly, and to territory which was mistakenly supposed to be friendly, as in the cases of the French expeditions to Ireland, and the landing of the Convict Brigade at Fishguard. Then we pass almost without a break to expeditions against islands known to be entirely hostile, and which yet were treated as operations neither requiring a commanded sea, nor communications.

But before considering such expeditions, which link up regular "invasions" at one end of the chain to such mere transferences of troops as we might imagine France making in war time from Toulon to Algiers, let us examine some of the conditions which differentiate marches like those of Wellington and Sherman, from such expeditions as those of Hoche from Brest to Bantry, or of Napoleon from Toulon to Alexandria. Wellington's and Sherman's marches would not have been contemplated unless it had been considered that the forces at the command of the Generals were likely to be the masters of any forces the enemy could send against them. They were defying the enemy to stop them; not evading him, and hoping in escape from him as the highest element of success. Hoche, Napoleon, and Ting would equally have objected to carry out the service had they not had reason to hope that they would never be met by the enemy in the course of their voyage. Wellington and Sherman sought battle with the enemy, looking on the prospect of his defeat if he were met as the greatest possible achievement of success. Wellington met his opponent at Vittoria; Sherman did not meet him because he was non-existent, but it would have been nothing less than a catastrophe in each case had Hoche, Napoleon, or Ting been met at sea before they had disembarked their troops.

The reason, of course, is that a combined naval and military expedition when at sea is in the most defenceless position. The military half of it is a great drag on the naval half of it, and a great source of weakness. The flotilla is not a fighting machine as a whole, like the armies of Wellington or of Sherman. It is a helpless convoy with an escort, which, being overcome, leaves the convoy—that under other circumstances is a great fighting power—a mere flock of sheep, entirely without means of defence. We get, perhaps, the strongest example that exists of this entire helplessness, in the sinking of the Chinese trooper *Kow-shing* by the Japanese cruisers, after they had dismissed her escort from the vicinity.

Such risks, which always attended the convoy of troops over an uncommanded sea, that is, over a territory which is not in military occupation by the power whose force is to be transported, seem to be doubled or quadrupled by the advent of steam. All those chances which the wind gave sometimes, as of favour to the convoying fleet, and of disfavour to the preventive fleet, are gone. Speed at sea has made all theatres of naval war so small that the Admiral in admitted predominance over it has an accurate knowledge of all things going on in every part of it, based on intelligence that is only a few hours old. There is no study of more advantage in this direction than that of the attempt of Hoche, as made possible by the chances of wind and the largeness, in time, of the theatre of war in his day, compared with the possibilities of our day, when the chances of wind are gone, and the theatre of war can be so rapidly surveyed by the 18 or 20-knot cruisers which the defending Admiral has at his command. I shall make this comparison in some detail later on.

It is curious to reflect how absolutely useless the escort of war-ships was to the French troops going to Egypt, and the Chinese troops going to the Korea. The sending of them was only courting the disasters of the Nile, and of the Yalu. In both cases the point was to effect the transfer without attracting attention ; and it was never to be hoped that Brueys could have secured Napoleon's transports against the attack of Nelson ; or that Ting could have secured his convoy against the onset of Admiral Ito. The only possible results were the attacks on the two fleets after the landings had been effected, unless the transports had been met and destroyed at sea. In both cases the proper course would have been to have caused the protecting fleet to have attracted the attention of the possibly attacking fleet ; by making a feint in some direction away from the route the troops were about to pursue. Thus the inferior fleet, avoiding engagement, would protect the passage of the troops without risk to itself. If the fleet protecting the transfer were superior, it would, of course, attack and defeat the fleet likely to hinder the transport of the troops, before despatching them.

In both cases of the French or Chinese transfer, it was the merest chance that the flotilla was missed at sea, on its way to the landing place. Nelson actually saw two of Napoleon's ships off Cape Passaro, but at the moment, his eager and excited condition, and his intense conviction that Egypt was the spot where he was to meet and destroy the enemy, did not suffer him to apprehend the significance of what he saw. Ting's and Ito's squadrons crossed one another's paths at sea.

In neither case, probably, could the attempt to transfer the troops in a great body have been made had the ports of Toulon and Ta-lien-hwan been watched in the way that experience had recommended in naval war, and which had been held in increasing significance as time rolled on.

But sufficient force of the right kind was not in Nelson's hands off Toulon, and he was prevented from even looking into the port, while the flotilla lay there, by a gale, which three or four smart frigates might have mastered. In the case of Admiral Ito, close watch of the enemy's ports did not form part of his policy until after the battles of Ping-Yang and Yalu. Ito's conduct shows that he very well understood the whole naval position, and I have good reason to think him a successful student of naval history. But his position was almost unique. The Korea was, in a sense, a neutral territory, into which the endeavour of both sides was to pour superior numbers of troops, and the Japanese Admiral seems not to have at first grasped the situation. If his fleets had been watching the few Chinese ports from which troops were likely to sail, and within which the warships of China lay, he would have been killing two birds with one stone. He would have prevented the sailing of the Chinese flotillas, and he would have secured the safety of the waters in his rear for the transport of his own troops.

In abstaining from any attempt to distribute his fleet in a watching position off the enemy's ports, and in employing it partly in convoy for his own transports, and partly in attempting to prevent —and in one case successfully—the landing of Chinese troops on the Korean coast, Ito took only the second best position. He permitted the inception of the idea of transfers of troops over sea in the Chinese Commander's mind, and allowed an actual transfer to be made, which he might have prevented.

But we must recollect that Ito's method grew up before war was declared. Probably, it was thought that watching the enemy's ports would be an act of war, and being postponed until after war had been declared was, by a sort of inadvertence, afterwards omitted.

The difficulties and dangers of these mere transfers of troops from friendly shore to friendly shore are much emphasized by the advent of the torpedo. In former days there did not exist any sudden means of destroying an enemy's transports. Capture, not destruction, was not only the end sought by an attacking fleet, but the only possible end, if the greatest amount of mischief was to be done. Now, in the case of these transfers, there must be instant surrender of the transports, or more instant destruction. The light and exceedingly swift torpedo vessels, which are coming more and more into vogue, are a terrible threat to enemy's troops found in transports at sea. It is almost impossible to conceive the horrors that would follow the meeting of a group of torpedo vessels and a flotilla of transports which did not instantly haul their colours down and submit to be driven, like a flock of sheep by sheep-dogs, in the direction whither the enemy shepherd desired. It is as easy to destroy a dozen *Kow-shings* as to destroy one ; and, by means of torpedoes, it will hardly take more time. The mere fact that torpedo vessels of superior speed exist, must, in future wars, make the inception of the idea of transferring troops over a sea which has not been first swept clean of them almost impossible.

But I promised to return to the case of West India Islands, which have been constantly invaded by troops carried over sea, which had no hopes of keeping up communications across it after they had been once landed. The war-history of the West India Islands, in fact, though abounding in strategical lessons regarding combined naval and military operations, is full of anomalies, and examples cannot be indiscriminately drawn from it.

The islands are generally small, and capable of being held by small garrisons, and, therefore, of being conquered by small bodies of troops. Hostile islands were constantly in juxtaposition with each other, and only a few miles apart. Circumstances so fell out that the garrison of an English island was far below its proper strength, while that of a French one near at hand was much in excess. It was easy to collect transport for a few hundreds of men ; with a trade wind fairly certain in force and direction, it was safe to assume that the passage across would not exceed a certain number of hours; boats for landing the small number of troops in a convenient and possibly sheltered spot were commonly available ; and the invading force was on shore almost before the garrison of the invaded island were aware of it. Rarely was the actual landing opposed. The garrison usually betook themselves into what constituted the citadel of the island, a more or less closed work, generally on a hill in the vicinity of the chief town and port of the island, but not generally on the shore. The situation then was that the invading force was in possession of the island and its supplies, all but the citadel. It had brought its guns and ammunition, and was ready to prosecute the siege of the citadel almost at leisure. Unless the citadel was capable of holding out for an indefinite time, there was no need of communications for the small invading force ; the island itself offered all necessary supplies, except amunition, and did that tend to run short it was only necessary, to reserve it, to cease direct attack, and wait till the garrison surrendered from want of food. But the citadel rarely held out for long. There was no object in holding out unless relief could come to it from over sea, and generally there was not much hope of that. So the citadel fell, and the invaded island passed absolutely under the dominion of the conquerors until another little army was landed which went through precisely the same operations, and ultimately re-took it.

Thus we have combined naval and military operations of three classes which have been, and may in future be, carried on over a sea which is not in military possession of the operating power, and without, therefore, any hopes of communication with a base. These three are—(1). Mere transfers of troops from one friendly shore to another. (2). Transfers of troops to shores which are contested between two land forces, and it is desired to assist one of them, as in the case of French landings to assist our revolted American Colonies, and in the case of the Chinese landing in the Korea. This class includes as a sub-class the landings of Humbert in Killala Bay, of the Convict Brigade at Fishguard, and, perhaps, of Napoleon in Egypt; and many others in the West India Islands where the populations were supposed to be divided against themselves. (3). Actual invasions of hostile territory consisting of islands with small populations and small garrisons, where force and supplies sufficient for the certain subjugation of the island could be suddenly landed after a short sea voyage.

While it becomes easy for us to see why these different forms of combined naval and military operations were conceived, and why they sometimes—perhaps generally—succeeded, I think it is made almost equally plain that steam and torpedoes must, in the future, put great restrictions on their employment.

If we study the history of opinion on the question, for instance, of the liability of the British islands to sudden invasion, we shall see that this opinion with regard to the effect of steam is quite a recent one, while I am almost stating the opinion with regard to torpedoes for the first time. We should not, therefore, have been surprised to note how much was made of the Chinese landing in the Yalu, as an argument in favour of liability to invasion, while so little —if anything—was made of the sinking of the *Kow-shing*. But if we go back five-and-forty years, and trace opinion onwards to near our own time, we can see that the habit of mind then was to neglect every consideration relating to defence by steam, and to dwell upon and expand every consideration relating to attack by steam. By some curious combinations of thought, the navy—notably in the Report of the Royal Commission of 1859–60—abandoned its traditional attitude and was quite content to assume that steam had made all forms of defence by sea impossible. No scientific study of naval history then existed. No one looked back into the causes of success or failure in former combined naval and military expeditions in order to ascertain what the effect on the conditions a different form of propulsion would have. The consequence was that when a steam war arose between the Federal and Conferate States of America, which showed more distinctly than anything else how greatly steam had added to the superiority of the superior naval force, little note was taken of it. The idea that steam had opened the territories of the superior naval power to attacks which were not feasible when the superior navy was a sailing navy had lain so long in our minds, and had so well established itself there, that it was not easily displaced. Even at this day it is almost common belief that the Federal steam blockade of the Confederate ports was much less effective than our sailing blockade of French ports proved itself in the wars of the past. Even now the certain fact that the decisive battle of the Civil War was that fought, near the opening, between the *Merrimac* and the *Monitor*, in the waters of the Chesapeake, is ridiculed.

It was, too, strange that it was seldom or never remembered that if steam had given these advantages to the attack on the defence, then it was to us, as the superior naval power, and not to France, as the inferior one, that they had been given. Our thoughts never turned in this direction at all. Nobody wrote about *our* combined naval and military expeditions. Everybody wrote of the dangers to which we were exposed by the naval and military expeditions of possible enemies. Nobody wrote of the dangers to which *they* were exposed by the increased powers of attack which it must have been logically admitted that steam had given to us. We were entirely occupied with thoughts of local defences, and gave none whatever to the general defence, which consisted in striking at the enemy's power of attack in its sources. It could not logically be denied that if steam had given the enemy increased power of attack on our sources of naval force, as Portsmouth and Plymouth, it must have given us increased powers of attack on French sources of naval strength, as Brest and Toulon. But we never once argued in this way. We put it almost in so many words that steam had weakened our power of attack, while strengthening that of all our possible enemies.

We thought exceedingly badly on the subject a few years ago, but there are plenty of indications that if we are not careful and diligent, we might easily fall back into thinking badly again.

One of the chief sources of our error was neglect to study and understand the conditions under which alone successful naval and military expeditions could be carried out. We accustomed ourselves to mix the three classes of expeditions that I have mentioned before, with that fourth class which consists in the attack on a distinctly hostile territory, requiring time, and secure communications over sea, for its successful issue. We constantly do this still. We constantly look upon our campaigns in the Peninsula, upon the battle of Waterloo, and upon the capture of Sebastopol, as if their success had rested upon a natural, and not upon an artificial condition of the sea. We habitually neglect to remember that the Federal success against Port Royal, Charleston Harbour, and the entrance to Wilmington; the Congressists' success against the Balmacedists in Chili; the Japanese success against Port Arthur and Wei-hai-wei; were all due to the preliminary creation of an artificial condition of the sea by the navies of the successful powers. More than this, we forget that none of these combined naval and military expeditions could have been conceived until this artificial condition of the sea had been first established.

There is something in the mind which has not been trained by a long sea life that generally makes this mere truism a hard saying to it. It is very difficult indeed for the non-naval mind to cease to conceive of the sea as an open and desert country, impossible of occupation by either of two belligerent forces, and over which, therefore, both are free to pass. The difficulty is not lessened by our almost unbroken record since the battle of La Hogue. We have had comparatively small experience of a sea of which we have not been in command, and it is something like a mental revolution to us to get into the frame of mind which is natural, for instance, to every French naval officer.

There are, I believe, no modern French naval writers who ever contemplate combined naval and military expeditions against England. The most advanced school starts with the proviso that such things are impossible to France, and that the *guerre de course* —a guerilla sea war, chiefly directed against our commerce—is alone open to her, but will be sufficient to bring us to our knees in the time to come.

So it becomes an undoubted condition that a combined naval and military expedition against a port, town, or territory, which could not, if entirely surrounded by land, be conquered by a flying column, must have secure communications across the sea.

This is really the meaning of the term "Command of the Sea," and it does not—cannot, in fact—mean that there is an absolute prevention of the appearance of an enemy on the line of communications. It really only means that they shall be as reasonably secure as those of an army must be before its commander will sit down to the siege of a fortress which is within the enemy's frontier. In fact, so far as I understand the matter, we have but to imagine land instead of water, and an army marching to reduce a land fortress, instead of a combined flotilla sailing to the attack of a part of the enemy's country, which borders on the sea, and you yourselves can introduce all the conditions which we in the navy think necessary to give reasonable hopes of success.

Napier, somewhere in his history of the Peninsular War, gives utterance to a feeling which was plausible, but mistaken on this head. While it never strikes him to doubt the security of the British army in the Peninsula as a whole—while he never seems to realize the fact that but for the security which the navy gave to the army in its communications with England, the latter must have collapsed—yet he expresses a sense of the danger which American privateers might have created in regard to particular supplies.

The fears were, as the event proved, chimerical; and they could never have been entertained by the navy. For the difference between a sea and a land line of communications is that at sea there is no lying across it and blocking it altogether midway between the base and the operating force, as there is on the land. To cut effectually a line of sea communications, it must be done where it narrows, that is, either close to the port which represents the base, or immediately in rear of the operating force which is making the attack.

What might be done by an enemy in the open sea, who has not force enough to take up either of the positions named, must always be a small matter, which will have little effect upon the ultimate result of the expedition.

It is, in fact, chiefly a question of degree, and I think almost equally so by sea and land. A general might discount occasional raids on small convoys, and an admiral might discount the action of an occasional escaped cruiser of the enemy, and proceed unshaken to the final accomplishment of their designs.

But without a reasonable security for his communications, we may be quite sure that every admiral will resist to the utmost of his powers, being joined in any combined naval and military expedition. It was always so.

It was very well for Hoche, backed by the absurd ideas of Carnot on the "Chouanerie" of the British islands, to force a scheme on the navy, which involved the employment of an immense flying column; the naval officers could predict for it nothing but disaster. Only one admiral at Brest could be found in hearty support of Hoche, and it seems clear that he had special reasons for affording it. Hoche could not conceive what the state of his mind would be as soon as the threat exercised by the invisible British fleet was brought home to him. With this one excepted admiral—who turned round before sailing—the naval officers about him did nothing but warn him and delay him by every means in their power. The first naval commander declined to go with him; the second never seems to have had any hopes of success. They knew from experience how different Hoche's ideas would be when he once started and actually felt the threat. Hoche blustered roundly about what he would do when he got to sea to such as should show any hesitation. He was not clear of the port before his frightened counter-orders threw his whole flotilla into confusion.

It is commonly supposed—historians repeating one another without independent examination—that it was a gale of wind which allowed the flotilla to sail; and that it was another gale which prevented the landing in Bantry Bay. Both suppositions are baseless. Colpoys let Hoche out by a course of action which was distinctly criminal, if he was not excused by his fears of being caught in the Bay of Brest by a change of wind which would place his fleet on the much dreaded lee shore. No admiral watching a port in war time was ever in a better position, or had better appliances for carrying out his duty, than Colpoys had. No one ever so wasted both.

It was entirely the neglect or the fears of Colpoys which allowed Hoche to sail; as it was entirely the fears of Hoche which led him to lose the advantage that Colpoys had offered him, and to complete the failure of the expedition. The "gales" in both cases only arose after the mischief was done. I do not doubt Colpoys' courage in the ordinary sense. It must have been the rocks about Brest that he was afraid of. Nor is Hoche's personal courage to be doubted. He had formed certain conceptions as to the absurdity of the notion of a commanded sea, before he had any experience of what it meant. He no sooner found himself at the head of a great combined naval and military expedition crossing a sea which was commanded by the enemy, than the whole truth flashed upon him and staggered him.

Nothing was to be seen of the enemy when the flotilla got under way from Brest for the last time but two British frigates, a force absolutely powerless to interfere. But it was what was not seen that troubled him. It was to him an entirely new sensation to march out into the dark without the slightest knowledge whether he might not run into the arms of a superior force within the next hour. He had formed no conception of the thing as it was, and he began to give vacillating orders which separated him from the bulk of his forces before the night had fully fallen.

And yet his fears were groundless. Colpoys, by his acts, was deliberately allowing him to sail, when he might have forced him to give up all hopes of sailing, or might have destroyed him after he had sailed.

The positions of Colpoys' fleet, quite capable of destroying Hoche's on successive days from the 10th to the 17th of December, 1796, are shown in *Plate* I. in circles surrounding figures. The nearest point to the Goulet of Brest that Colpoys ever reached was that gained on the 10th, and it was 25 miles distant.

When Colpoys was on the 10th in this position, he knew—for Pellew, who was watching Brest closer in, had told him—that there were 18 sail of the line ready for sea in the outer road of Brest. His whole duty was either to prevent these ships coming out, or to destroy them after they came out. The wind was then fair for their coming out. It was moderate, and the weather was fine and clear. There was nothing but fear of some kind to prevent him from maintaining even a much closer position than the one he held, and no danger attached to it, unless the wind changed; but if it changed, it would prevent the exit of the French.

His action on the merits of the case is incomprehensible. He sailed away to the North-West, and on the 11th, at noon, was in the position shown, 24 miles to the North-West of Ushant, and 45 from the fleet in Brest, which it was his duty to keep in touch with. But then, on the other hand, he had left Pellew with six, or perhaps seven, frigates and small vessels closer in to Brest. That is, enough fast sailing vessels to keep him constantly informed of the enemy's movements, and *provided he always sent them back again after they had reported*, enough to dog the footsteps of the enemy in case they put to sea, and to fathom their designs, as was done later with a smaller expedition of the same character.

The plot thickened. Pellew saw Richery's squadron enter Brest through the Raz de Sein on the afternoon of the 11th. It was understood that this would hasten the sailing of Hoche's expedition, and Pellew sent one of his ships to report to Colpoys, and another to the Admiralty. Colpoys did not get the report until 11 a.m. on the 12th; he was then in the position shown, 30 miles west of Ushant, and 50 from Brest. There was nothing at all but his own will to have put him so far off. The weather had kept fine, the wind light or moderate from the eastward, but now hauling round to the south-eastward. Even so he made little attempt to close with Brest, and all through the night of the 12th made none at all.

On the morning of the 13th the weather began for the first time to turn against him. The wind freshened, and drew more to the southward, yet Colpoys made no efforts to press his ships, and having small fast vessels with him, kept them instead of sending them on to Pellew. Two of Pellew's frigates having been sent out to him, he kept them also. These ships brought news of the more imminent sailing of the French, but Colpoys never pressed his ships, and never even made a determined attempt to get to the southward. At noon on the 14th he was 33 miles west of Ushant, and 45 from Brest, with three frigates that he might have sent in to assist Pellew, but did not.

Pellew's practice was to beat up every night so as to get as close as possible to the Goulet, and to Bertheame and Camaret Bays, where the enemy was assembling as they came out of Brest, early the next day. A strong force of the enemy always got under way and chased him out, but he always turned as they ceased to chase, and worked back again.

On the 15th Colpoys was 33 miles S.W. of Ushant, and 45 miles from Brest, and he had left Pellew with only three frigates and a lugger, which Colpoys made him send to him in the forenoon.

By one o'clock in the afternoon Pellew had got close up to Brest, and before he was, as usual, chased off, he had counted 23 sail coming out of the Goulet, and he saw them anchor in Camaret Bay. Before the day was out Pellew knew that there were 16 sail of the line, 11 frigates, and 16 transports with Hoche and his troops on board, all outside Brest and ready to sail at five minutes' notice. He sent off one of his three frigates to inform Colpoys, and went on watching with his two.

Up to now, the weather had never been such as to prevent Colpoys from pressing up. Such frigates as he allowed to go back to Pellew never had any difficulty; but now, on the 16th at noon, he had so managed matters that, with the French on the point of starting, he was 65 miles from them, being 45 miles west of Ushant. Pellew's frigate gave him the news at 10 o'clock in the forenoon, *but he did not send her back;* he kept her with the six other frigates and small vessels he had with him, which if Pellew had had would almost certainly have followed Hoche up, and enabled Colpoys to fall upon him at sea.

That afternoon the French expedition sailed. Pellew sent his one frigate to inform Colpoys. Colpoys, however, was not found, because he was five and thirty miles to the north-west of where he was expected to be, and where he might have been if he had chosen. There was no gale of wind. The fleet could set top-gallantsails up to the afternoon of the 16th. The historians "gale" did not begin until the morning of the 17th; 10 hours after the French had put to sea.

I wish to draw your attention particularly to these facts.

The French had no sort of reason to believe that Colpoys would so fail. Pellew himself could not conceive it possible that Colpoys would behave as he did, making no effort to close with Brest; keeping all the frigates with him where they were useless; allowing his fleet to stray 30 or 35 miles beyond his rendezvous.

You can see that Colpoys twice repeated the manœuvre which was most calculated to let the French fleet out, by clearing the entrance to Brest; once between the 10th and the 11th, when he did it most deliberately; and once between the 15th and 16th, when, if he did it less deliberately, he certainly suffered himself to do it.

The point, of course, is that while we are rather accustomed to regard the escape of Hoche as showing the difficulty of keeping a combined naval and military expedition in port, we ought really to think of the extraordinary chance by which Hoche escaped; and to remember that Colpoys ought to have no more difficulty in preventing his sailing than Cornwallis had in preventing Ganteaume from sailing, eight years subsequently.

Then, too, we have to note, that if it was an extraordinary chance by which this combined naval and military expedition got to sea in the days of sailing ships, we must see the impossibility of doing it in the days of steam unless the torpedo is found to entirely alter the conditions. For while, in the days of Colpoys, the case was so little understood that the Admiralty did not even make a remark about his dating a letter 60 miles from Brest to inform them that he had every reason to believe the French fleet was at sea—he did not know where—an Admiral in command of a steam fleet might have to answer with his life for so writing under such circumstances.

But then Hoche had got to sea, and, to what must have been the astonishment of the naval officers—in spite of the foggy weather—without seeing an enemy except the two frigates which had fallen back as the flotilla came out. What then was to hinder success? We must answer, nothing in the weather. The first frightened mistake of counter-orders had not after all mattered to the bulk of the ships. The flotilla, notwithstanding that the fear of the British fleet did not allow it to steer straight thither, quickly reached its destination; 36 out of the 43 ships were, at daybreak on the 21st of December, at the rendezvous, off Mizzen Head, in beautiful weather, and with a fair wind to take them right up Bantry Bay. What prevented them from sailing right up and landing the troops that afternoon?

This did. The Commander-in-Chief was not there. His vacillation in leaving Brest had mattered to him, and he was behind. When he did see the coast of Ireland, he saw also—or more probably, I think, thought he saw—a British war ship in chase of him. He fled from her at such a rate, and so far, that he did not get back to the coast of Ireland till the 8th of January, when nearly all his ships had gone home.

I cannot but doubt that Hoche imagined the chase, for I have looked up the logs of all the likely ships, and I cannot find out what ship it was that chased him.

The fact, at any rate, remains that the failure of this naval and military expedition, though it was arranged as a flying column, was not due to accident. It was due to accident that it ever put to sea. After that, accident ceased. Its success would have been the accident. Its failure was due to its insecure communications. In other words, it was never safe from overwhelming attack from the moment it started; and I need not point out that as no purely military expedition could be undertaken in such conditions, neither ought any combined naval and military one to be proposed.

And if we are to say distinctly that Hoche's expedition ought never to have started—that the real wonder was that it ever accomplished what it did, and richly deserved a much more disastrous fate—how much more plainly can we see the impossibility of the French even conceiving the idea of such an expedition in the days of steam, provided we can show as good a force of the right kind as Colpoys had?

Setting aside, for the time, the profoundly interesting question of torpedo boats and their effect on a watching fleet, we see that the modern Colpoys would have neither reason nor excuse for these wanderings from his post. It would be the simplest thing in the world for him to take his fleet up daily to a position closer to Brest than even Pellew's frigates took. Indeed, Lord St. Vincent, at a later date, almost did this with a sailing fleet. Such a display of force would equally now, as then, preclude the sailing of a combined naval and military expedition, supposing it were ready to sail, but the knowledge on the part of the enemy that it would be so would certainly prevent the inception of the idea of such an expedition. It was most unusual, at the close of last century, to attempt to watch Brest at all in the winter, and, doubtless, that consideration had to do with Hoche's hopes. We can recall how, in our manœuvres of 1889, Sir George Tryon had to make a feint with his whole fleet against the squadron blockading Bantry, in the dead of night, in order to get only three ships to sea. It would not have been possible for him to have got out a larger force.

But the conditions are now such that this showing of force off Brest in order to prevent the preparation, or the sailing, of a combined naval and military expedition thence, is no longer necessary. The modern Colpoys, lying with his fleet behind Plymouth breakwater, would be in much closer touch with the enemy at Brest than Colpoys ever was. The modern fast cruiser, and still more certainly, the modern 30-knot torpedo-boat-destroyer, would run from the outer waters of Brest to Plymouth and back in a much shorter time, and with infinitely greater certainty, than was possible to Pellew's frigates in their communications with Colpoys, even when he was on his rendezvous.

And if we are to admit, for the sake of argument, that the knowledge that things are so, would not operate on the mind of the French, and that a modern Hoche might again prepare an expedition on the old lines, we have to pursue the comparison a little farther.

Brest, under the hypothesis, would only be watched by a swarm of vessels capable of running to Plymouth and back in ten or twelve hours. The former Colpoys may have had some vague reasons for keeping the frigates when Pellew sent them out to him. None could exist to move the modern Colpoys to keep his fast vessels in Plymouth Sound, because his chief source of intelligence—except with Brest, perhaps—would be the telegraph. But supposing that the modern Colpoys in Plymouth Sound was not in closer touch with Brest than by means of his fast vessels, bringing him intelligence five or six hours old; and supposing the sailing of the modern Hoche within these five or six hours; what then?

Suppose the modern Colpoys as ignorant of the destination of the flotilla as the real one was, and acting just as the real one did; then, as the real one remained stationary, waiting for intelligence, so would the modern one. In a quarter of an hour after the modern Hoche had appeared off the coast of Ireland, the modern Colpoys would know it, and in half an hour he would sail, timed to reach Bantry in 18 hours.

The one thing which steam and modern appliances have had little or no effect upon is the time required to land troops from transports. Steam pinnaces have done something in hastening the passage between ships and shore, but the speed of a landing still, as ever, rests on the number of boats available; the rate at which troops can get into them from the transports; the rate at which they can disembark, which depends, of course, much on the convenience and extent of the landing place; and the weather.*

Now, war ships are no longer available, as they were in Hoche's time, for the conveyance of great bodies of troops, and while the size of steam transports enables a greater body of troops to be carried in fewer bottoms than was formerly the case, the fact tells against the speed of a landing. Troops cannot quit a single ship at the same rate at which they can quit a dozen ships. The modern Hoche could not count on landing his men any faster than his exemplar could. And then the weather, which perhaps assisted to prevent Grouchy from landing the mere remnant of his force at Bantry, would equally prevent the modern Hoche from doing it. No doubt if we suppose a modern Hoche determining to go through with it, though he could only calculate on 19 hours' freedom from the moment of sighting land, he would endeavour to time himself so as to make the land at break of day. In such a case he would expect his Colpoys to be on him by the evening for certain. But a modicum of thick weather in the morning would indefinitely delay the modern Hoche's approach to the shore; and if the modern Colpoys at Plymouth got his telegram in the afternoon instead of in the early morning, the modern Hoche would know that all the night while he was perforce idle, his enemy was making for him at

* The Japanese took 12 days to land their horses for the attack of Port Arthur.

15 knots an hour, and certain to catch him in the middle of his disembarkation.

But, of course, we may assume that when the modern Colpoys got news from Brest of the inconvenience of the sailing of the modern Hoche, he might proceed to a rendezvous off Brest.

It was a feature in the actual escape of Hoche, that when Pellew sent his only frigate to announce to Colpoys the sailing of the French expedition, and when he followed up himself after losing sight of the French, neither he nor his frigate ever found Colpoys at all. The reason was that Colpoys was some 30 miles away from his station. We require to know whether such a thing could happen to a modern Colpoys, and a modern Pellew, and the answer is that it could not. It would be a shooting or hanging matter now for an Admiral to be off his station as Colpoys was on the morning of the 17th of December; but if he was, a single cruiser would be bound to find him in a very short time. Pellew and his other frigate missed him because of the excessively slow speed at which it was alone possible for them to "quarter" their ground. A single 15-knot cruiser, working round from a centre, would now explore the area of a circle 60 miles in diameter, within 5 miles of every point in it, in about 15 hours.

Then again, assuming the modern Colpoys to be thus easily and rapidly found at sea, and that he had with him, as the real Colpoys had, the bulk of his fast cruisers, and news of the sailing of the French, say 5 or 6 hours old—though it could not be so much—a cruiser could have gone to Cork and been back again in 24 hours; another could have gone to Bantry and been back again in the same time; a third could have communicated with Scilly, and have rejoined him in 12 hours; while a fourth and fifth could have scoured the sea to the southward and westward, almost certainly gaining intelligence from some of the stream of merchant steamers constantly flowing thence Channelwards. For it is not with a steam fleet as with a sailing fleet. Then the ships must actually be seen to be discovered; now the smoke discloses their whereabouts hours before the ships themselves become visible.

We are led by the contemplation of this mistake of the French to remind ourselves that the opinion of one service never ought to be allowed to override that of the other. Both our views must be highly technical. The men of each service have been for years contemplating, studying, and experiencing one set of conditions, and it is impossible, short, perhaps, of interminable explanations, to make each other understand all the reasons that influence our opinions. The only safe plan is to take care, before a joint naval and military expedition is determined on, that both army and navy agree that it is feasible. Napoleon was always forcing the hands of his naval advisers, always considering—like Hoche—that he knew better, and always coming to grief over it, great genius as he was.

When we can anticipate a secure line of communications over sea, and when the naval and military commanders are agreed on the feasibility of the enterprise, the primary conditions of success are established. It is then only a question of the proper amount of force and material.

Generally speaking, the troops embarked for a combined naval and military expedition have been largely in excess of the garrison to be attacked.

General Stanhope took 2,600 men for the attack on Minorca in 1708, which had a garrison of only 1,000. In 1756 the Duc de Richelieu took more than 12,000 against the same island, when it had not more than 3,000 men as a garrison. In 1781 the Duc de Crillon took 10,000 men to overcome the 2,700 men that formed the English garrison of the same island. The proportions were less in our capture of Louisbourg in 1745, when we attacked a garrison of 1,200 regular troops with 3,850 raw volunteers. For the capture of Belleisle in 1761 we required 10,000 troops against a garrison of 2,600.

Such expeditions as these form a class which nearly stand as flying columns. Though it is not safe to undertake them without a free line of communications, yet, as the whole of the necessary force goes together, the line is not used. Nevertheless, the risk that is run in the matter of communications, when their freedom has not been made perfectly sure by the naval force, has often been illustrated. It was a mere chance that the Duc de Richelieu did not lose his whole army in Minorca in 1756. If Byng had been victorious he must have done so.

And then, if by the temporary absence of the defending naval force such captures are made, the possession is never secure. When the superior naval power, with her fleet, cuts the communications, she is nearly certain to follow it up with the re-capture of the place, and no advantage has ultimately accrued to the original attacking power. The notable cases of this kind were the re-capture of Malta at the end of last century, and the surrender of the French army in Egypt at the beginning of this. Apparent successes, which are afterwards reversed, are the most terrible drains on the power of a belligerent. She suffers directly in the loss of her troops, but perhaps even more by the revulsion of her feelings and the loss of her prestige.

In a general way, it may be said that combined naval and military expeditions are divided into four classes, which may stand thus in order of their importance :—

1. Punitive expeditions, often conducted up rivers and estuaries, and commonly against uncivilized enemies.

2. Captures of islands, which may be done by the dispatch, once for all, of a sufficient force.

3. Captures of ports which it is intended to hold by means of communications over sea, without necessarily holding the surrounding country.

4. Invasions, where the actual conquest of the country is intended.

We are continually engaged in this first class of expeditions ; they are, as a rule, on a very small scale, and are carried out as it were locally, by the troops of the nearest garrison, in the boats of the ships immediately at hand. Except that the sailors provide the boats and the means of propulsion, there is in such expeditions no distinction to be drawn between the functions of the army and the navy. Now-a-days, our seamen form a body of excellent and perfectly reliable light troops ; and soldiers, marines, and sailors land and proceed to the attack on a footing of perfect equality, all under the command—as soon as the shore is reached—of the military officer commanding the troops.

The success and rapidity of such expeditions have in our day been greatly facilitated by steam boats, and machine and quick-firing guns. Instead of boats being pulled with difficulty against the stream, the oars are laid in, and the steam pinnaces draw a string or train of boats after them at great speed, and with perfect ease.

The speed at which these trains proceed, and the freedom to use their rifles, which the absence of the use of oars allows, gives a security in passing up narrow streams with jungle-covered banks which did not exist in former days. When progress was slow, and the boats' crews were labouring at their oars, there was often a fear of great loss of life from ambush under cover on the shores.

I have dwelt a good deal on the principles involved in the capture of islands already. If a layman on that subject may hold an opinion and express it, I may say that reading the history of such undertakings leads me to think that the best passive defence is that which in old days used to be adopted. A citadel fortress on a height well removed from the sea appears to me to have always offered the greatest obstacle to an attacking force.

It is obvious that an island on which a sufficiently superior force to the garrison has been landed, with secure communications, must fall, sooner or later. Its only hope lies in the possibility of the enemy's communications being cut by the arrival of a relieving naval force. In other words, if the garrison and works upon an island do not absolutely preclude attack, both together can only offer delay to capture.

Sea-faced works, of which the communications over sea are closed, have the disadvantage that their investment requires perhaps only half the number of troops that would be required for an inland fortress.

Again, although now less than ever is it to be expected that war ships will seriously attack even light sea-faced works, yet by way of diversion, the attention of the garrison of a sea-faced fortress may be successfully distracted by the distant fire of a few ships.

The course of history shows that an enemy landing on an island can never feel himself secure in any part of it so long as the garrison in the citadel remains intact. He will bend the whole of his energies to its reduction, and, of course, before he contemplates attack at all, he must be prepared with sufficient troops to surround the citadel—greater numbers being required for this service when the citadel is inland than when it is on the sea.

No doubt such an inland citadel should command the port. But it does not seem to me that it is necessary to command the entrance to the port. An island citadel inside the port, and not necessarily commanding the entranee, has always offered a surprising resistance to attack, as may be noticed in the instances of the island battery in Louisbourg Harbour, in 1745; Fort Sumter, at Charleston, in the American Civil War; and the island of Leu-kung-tau, at Wei-hai-wei, the other day.

The landing of an expedition for the conquest of a small island is generally an easy task. There is no need to hurry it if the communications are safe, and it is almost certain that there should be convenient landing places. The landings at Minorca were made at different points, at different times; and, of course, the smaller the force is, the more easy is it to find convenient landing places.

The expedition, as a combined one, is practically over when the troops, with their supplies and material, have been put on shore. The only other help the navy can give is to blockade the ports, and, as just observed, create a little diversion by firing on sea-faced works from a safe distance. This advantage is, of course, lost if the enemy trusts to an inland citadel.

Some years ago I was led to the conclusion that steam had made the capture and retention of the enemy's continental ports much more easy than it ever could have been in the days of sailing ships. The case of Dunkirk reminds us that such an operation was not unknown in the early days; and Cadiz, and Lisbon behind the lines of Torres Vedras, show us how ports open to the sea, if once in the hands of the power commanding it, could, even in the days of sails, be held against all comers from the land side.

But the coolness with which the Federals, in the American Civil War, extended the principle when they had steam in their hands, shows us that the power which holds a steam command of the sea will probably soon begin to indulge largely in this sort of operation.

It was common talk amongst us, in the Navy, when the declaration of war between China and Japan was expected, that if Japan could beat the Chinese fleet, and so secure her communications, she would make an early and successful attack on Port Arthur. When the battle of Yalu was fought, we considered that the combined naval and military expedition which was certainly in preparation, would be directed against Port Arthur.

I think that many of us are disposed to consider that the rapid and easy fall of this port and that of Wei-hai-wei ought not to be set down wholly to failure on the Chinese side. I myself understand that the most skilful of military nations, deprived of her command of the sea, would have lost Port Arthur to the sort of attack made by the Japanese; not, perhaps, as quickly as the Chinese did, but still with surprising quickness.

The situation of Port Arthur, at the end of a long peninsula terminating in a promontory connected to it by a very narrow neck of land, offered every facility to attack by a combined naval and military operation.

If we think of the captures of Louisbourg in 1745 and in 1758, side by side with the capture of Port Arthur, we shall find that—except for a different system of fortification—the lapse of years, and the advent of steam and rifled ordnance, has made no difference in the method.

Having secure communications, the assailants in America and

China seek out smooth water landing places, where there are no forts, and where the ships can, if necessary, cover and support the landing. The British found it in Gabarus Bay, and the Japanese near Pits-wo, a place not far up the coast to the N.E. As soon as they are ready the British and Japanese march to their objective. The narrow neck of land between Ta-lien and Kinchau Bays offered, on the one

hand, peculiar facilities for defence by the Chinese land forces, but at the same time, the special weakness of being flanked on both sides by the Japanese war ships. It was not seriously defended.

Meanwhile, the ships of the British and Japanese assisted the attack by blockading the ports, and to a small extent by firing on the works. But just as a portion of Admiral Ito's force was watching the Chinese fleet in Wei-hai-wei, so, in 1745, was a British force masking the French expedition destined to relieve Louisbourg, in Brest, in 1745.

The speed of the Japanese in making the capture of Port Arthur was no doubt greater than that of the British in capturing Louisbourg. The Japanese began to disembark on October 24th, and the place fell on November the 21st, that is, in twenty-seven days. Louisbourg fell in forty-seven days in 1745, and in forty-five days in 1758. Regarding the improvement in weapons, we can scarcely say that it greatly hastened the Japanese proceedings.

The attack on Wei-hai-wei was on the same lines. There was a combined expedition till the landing was complete at a point distant from the objective; sheltered, and free from fortifications. There the army was left to itself, the navy confining itself, as far as the works of Wei-hai-Wei were concerned, to the diversion of a distant bombardment. But the new weapon, the torpedo boat, was used effectively, though not without loss, against the ships in the harbour. The ships and the island citadel held out, at Wei-hai-wei, long after the whole of the land fortifications were in the Japanese hands. Fear of submarine mines will generally be effective to keep the costly ships of the present day out of possibly obstructed waters; but, in any case, the relative cost of batteries and ships is so immensely against the ships that the circumstances must be very pressing indeed when ships willingly submit themselves deliberately to land fire.

Very little need be said of that form of combined expeditions which we more especially particularise by the name of invasion—the more or less sudden landing of a great army on a stretch of open beach.

Our modern instances, curiously enough—the invasion of Egypt, of Algeria, and of the Crimea—have all been carried out in a tideless sea, and we are apt to forget the difference in difficulty between landing in the Mediterranean and in the Channel, for instance. But in either case a combined naval and military force cannot dare to act without full control of its communications. The difficulty of this sort of landing is that it is impossible to guarantee a given time within which it may reasonably be hoped to effect it. It is curious that, even in the tideless sea, each invasion was delayed by the surf. The landing in Egypt was delayed five days from this cause; the landing in Algiers by the French was delayed nineteen days; and it is always well remembered that our own landing in the Crimea broke down on the first evening. If it had been feasible to attack the imperfect part of the army landed, it is extremely improbable that, cut off from the fleet as it was, it could have received the slightest assistance from the ships. It does not require locally bad weather to make a beach impracticable for landing on. Rollers set in at any moment, and at different times of tide, without any assignable cause, and make it either quite impossible, or excessively dangerous to proceed with the disembarkation. And with much rise and fall of tide all the dangers and difficulties are increased ten-fold.

Seamen, with free choice and secure communications, would, I think, more generally commend the plan agreed on by the Duke of Wellington and the Admiral for the landing in Portugal. That is landing slowly, as at Mondego Bay, in a continuous stream upon the most sheltered spot to be found. The landing at Mondego Bay was none too easy as it was, but there was a good deal of shelter.

And I think it would generally be considered that if the conquest of a country were determined on, the seizure of a port, by the methods already described, ought to be the preliminary operation. The sailors and soldiers must discuss together the question of the possibility of capture. The sailors would point to the suitable landing places in the vicinity of the port not protected by fortifications, which are generally to be found. There they would be prepared to disembark the troops under cover of the guns of the ships, and afterwards to preserve the stream of recruitment and supply until the port itself was gained.

The soldiers would have to determine whether the surrounding country was such as could be entrenched and held against probable attacks of the enemy, and whether the route to the port was suitable, and could be made secure until the port itself fell.

We have, of course, as our type, Balaklava and Kazatch, only we should think of beginning the landings there by deliberate choice, not by taking up the ports later, by way, as it were, of second thoughts.

We are to suppose that we have not undertaken so tremendous a task without preparing an immense force, and without being reasonably sure that after we had got the port, we could, having the sea open behind us, hold it, and gradually extend our frontier.

The key to our power of doing all this must be our capacity to assemble troops on the spot by advantage of the sea roads, at a much greater rate than the enemy could assemble his over the land roads. I suppose the selection of a port for capture and holding in this way would depend a good deal on whether many or few lines of road and rail concentrated upon it; and, I presume, one of the earliest duties of the army landed would be the breaking down and destroying, by means of flying columns, any facilities of approach which the enemy might have in this way.

I presume I am not wrong in supposing that if we were unfortunately at war with a great power, it would be peculiarly the province of the Royal Engineers to determine the feasibility of the different land operations in the attack on any particular port which might be suggested, before any such attack could be decided on.

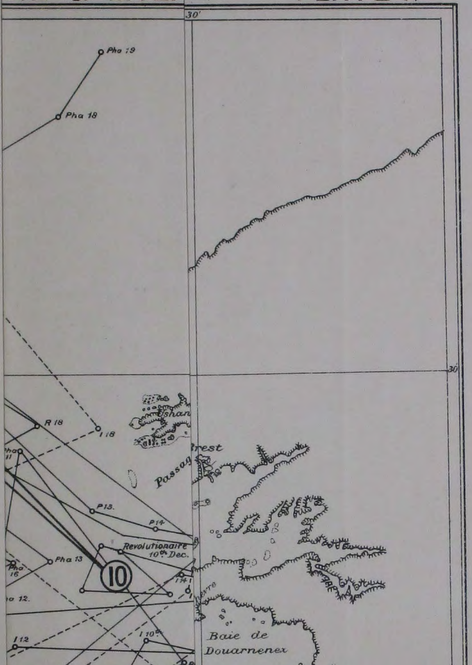
These attacks upon ports indeed, seem to stand out more and more as the main objects of the superior naval power as we consider the subject; while, of course, they recede in possibility to the modern inferior naval power.

In the American Civil War a main object in these attacks was the perfect closing of the ports to blockade-runners outwards and inwards; and to us that closing, as the only complete method of protecting our commerce, might become a primary necessity. Although it seems certain that modern appliances for "observing" a naval and military flotilla in an enemy's port are complete enough to prevent their assemblage, yet it does not seem that ordinary blockade can altogether bar the way of the swift cruiser at night. If the game should be sufficiently worth the candle—which, however, cannot be predicted—there might be no way of blocking absolutely the exit and entrance of the commerce-destroyer, but by following the example of the Federals, and absolutely possessing ourselves of the outer waters of the enemy's ports. This would give a reason for such attacks, which might not exist if the object were simple possession; and on the whole I cannot but think that the study and examination of such attacks from the moment of landing to the moment of ultimate success—questions on which the navy knows little—might be worthy of the closest attention of the Royal Engineers.

I have once or twice mentioned the only modern condition which seems to tell against them. I mean the possible use which an enemy might make of his defending torpedo boats and vessels.

I trust that in taking the wide and general view that I have done of the nature of combined naval and military operations, I have been able to some extent to meet your wishes. In a former paper, which is printed in the Confidential Series of your *Professional Papers*, I went perhaps more into detail, and that fact induced me to take the more general view on this occasion.

AL & MILI PLATE I.



PAPER II.

THE DEFENCE OF PLEVNA.

(*Lecture delivered at the School of Military Engineering, Chatham, by* WM. V. HERBERT, ESQ., *on the 16th January,* 1896).

I THINK I am justified in commencing in the orthodox fashion, that is, with an apology. There are three grounds on which I claim your indulgence:—Firstly, I suffer under a total lack of theoretical teaching and training, having been brought up to a peaceful profession, with no eye to battery and assault; secondly, I have had but one experience in the field, the Plevna Campaign, am acquainted with but one army, the Turkish, and know of other wars and other armies no more than that to which anyone may attain by study; and, lastly my knowledge of English is an acquired one. One of the deductions which you will draw from these facts is that I am insufficiently acquainted with technical terminology. If, therefore, I should at any time use a phrase or expression which may sound flat, brief, and commonplace, and but a feeble substitute for an euphonious technical term of many syllables and foreign make, I solicit your forbearance.

To atone for these obvious deficiencies, I have seen the real thing, and that—I am sure you will all agree—is better than the most profound knowledge of the most abstruse nomenclature, better than familiarity with all the theories ever invented.

Having been honoured by the unsolicited and undeserved request to lecture at this School, I made up my mind to present to you little or nothing of what I have already stated in my volume on the defence of Plevna, which, I understand, is at the disposal of any of you who care to read it. Should I, nevertheless, appear guilty of occasional repetition, I must justify myself by means of the undeniable adage that facts and truths cannot be reiterated too often. To mention but one instance of this maxim as applied to the subject of warfare. It has been spelt and spoken, ruled and written, preached and printed times out of number in every European language, and ever since the battlefield was made the basis of statistics, that the losses in attack, in a charge, in any forward movement on the field of "blood and mud," are smaller than those during a retreat, or (worse) during a flight, in fact, during any occurrence with a retrograde tendency, and if it be only a temporary check in an assault.

Figures do not lie, and figures have proved and demonstrated this. My brave and honoured former enemy, Captain (now General) Kuropatkin, of the Russian army, Skobeleff's Adjutant in 1877, has emphasized, over and over again, this plain fact in his admirable book on the Plevna Campaign. Hoenig, the best known and most prolific among the many German military writers, insists upon this truth in almost every chapter of each work of his, and many other authors of light and leading have illustrated it with facts and figures. Yet, what happens on the field of battle? A charge is undertaken, somehow it is checked half-way, and men who know perfectly well what all those writers and authorities have pointed out, whose teaching and training has instilled it into their minds—or ought to have done so—whose reading has persuaded and convinced them, forget that it is less dangerous and fatal to advance toward the goal appointed than it is to return to the starting place, and because the first rush has been checked they retreat, maybe they run back, with the result that the battalion, instead of taking the hostile position at a cost of, say, one hundred men, loses three hundred and fails. The reason is not far to seek. In the tumultuous devilry of the battlefield the human mind asserts itself almightily—I mean that portion of the mental constitution which acts upon impulse at the cost of the other part acting upon teaching and formulated rules. This deficiency can be overcome—to my way of thinking—only by the self-training of the mind, which a constant study (I allude to voluntary studies, apart from the discipline of the school) of similar experience in the past involves, in other words, a rigid and continuous course of history. To make the experience of others our own to such a degree that in the wildest moments, in the most unforseen and unprovided-for occurrences, amid the most distracting surroundings and circumstances, aye, in the very teeth of death, we act upon it by instinct or tuition, should be the aim and goal of everyone who takes the pains to study military history, and that is a prize well worth winning.

I propose to review briefly the historical events in which I had a humble share, with cursory comments thereon, and deductions therefrom, if I consider that any particular situation might furnish useful hints to those placed in similar positions.

In all that I have to say to you I must disclaim any intention of laying down hard and fast lines, of dogmatizing, or of establishing indisputable points. Having been invited to state my opinion, as based upon personal experience, I shall do so according to the light that is within me, though I freely acknowledge that many of you—who are, perchance, immeasurably my superiors in wisdom, natural or acquired—may draw deductions different to mine.

I beg of you to consider also that I was but a very small pawn in the great game of which the board is an empire, the stake the fate of nations. But although this fact will explain the unavoidable absence of a broad and general view, of the grasp of principles on my part, it will also help to place before you some details which those never behold who see only the ornamental fringe of warfare.

The first phase of my experience which I shall present to you is my march from Bellova, at that time the terminus of the railway, to Widdin, where Osman Pasha, the hero of the Servian campaign of the previous year, was stationed with his army during the first half of 1877.

I would draw your attention to the numerous, manifold, and thoroughly methodical preparations made for this journey, which had a road-length of about 200 miles and was accomplished in 20 days, an average of 10 miles per day. Three-fifths of that distance lay across mountainous country, including that most trackless, inhospitable, and forbidding of European mountain ranges, the Balkans, and withal the roads, or rather tracks, were bad, sometimes execrable, soaked by the recent rains peculiar to the spring equinox; for we were in that treacherous month, April. The weather, however, was unexpectedly fine, and the only meteorological disadvantage under which we had to labour was the coldness of the nights, with the icy north winds characteristic of that country. A march of this description is a serious affair, and ought to entail a severe course of preparation, as it did with us; for on this occasion the Turkish arrangements were quite admirable.

"Wars are won with the legs," or, to express it differently, a soldier's chief implements of trade are his feet. This was acknowledged by the authorities of Bellova camp, and I was instructed to inspect the feet of 200 men in my charge, and weed out the unfit. Some time before the start I had insisted on a daily foot-bath, and an occasional bath in the river. To cure sore feet I concocted an ointment. For the benefit of those placed in similar positions (that is, without capable medical supervision and apothecaries, and almost without drugs) I shall state my recipe, which I found to be extremely efficient.

The fat of the uncooked mutton-joint is to be melted almost (but not quite) to boiling point in a clean copper or pewter vessel, with just enough water added to cover the bottom of the vessel. Of course, only the fat of unsalted meat can be employed, for that of salted is irritating. Then I used to add: firstly, a small quantity of new milk (to keep the compound semi-liquid when cold; the proportion was about one measure of milk to four measures of melted fat); secondly, a drop of attar of roses (which was cheap and plentiful in the country; but any common essential oil, such as Bergamot, will do as well); and thirdly, a pinch of permanganate of potash, no more than to colour the compound a faint pink. Those are all the ingredients. Stir well and let the mixture cool, and carry it with you in the vessel in which it has been made, if there be a cover to it. The purpose of the attar of roses was, of course, to render the concoction agreeable to the nostrils, and thus cause ignorant men to take to it kindly and without compulsion—which latter, in my experience, is always to be avoided where physicking is concerned—and the effect of the permanganate of potash (sulphate of zinc will do the same service) is to prevent the mixture from turning sour for at least eight or ten days. This ointment I caused to be made afresh every other day during the march, and to be used night and morning. It can be prepared without any extra trouble during the dinner hour. As I am on the subject of physicking, I might mention a simple but efficacious preventative medicine in case the skin disease vulgarly known as "the itch" (that curse of the mud huts, at least with us) should be prevalent. Take a quantity of the leaves of the evergreen shrub called arbor vitæ which is familiar to all of you, and is to be found in abundance all over the globe wherever people have front gardens, boil them thoroughly, strain and sieve the liquid, and wash yourself with it and the treble quantity of clean cold water as often as you like, but thrice a week would be sufficient for the present purpose—either with or without soap. In my experience the vermin fights shy of any skin flavouring of this concoction. A little sulphur may be added with advantage, but if your drug stores be at low ebb, the essence of the leaves pure and simple will do quite as well. One more homely medicine for campaigning purposes. Do not throw away the peel of pears and apples, but boil it, and the tepid water will make a very grateful, refreshing, and beneficial wash after a forced march or a hard day's fighting. It is, in fact, a crude, but quite efficient, substitute for the toilet vinegars dear to the weaker sex.

Our preparations included the dealing out of mufflers, blankets, towels, and large cotton handkerchiefs, one of each article to each man. We carried six days' biscuit rations with us, which were stowed in a large canvas haversack. I caused my men to wash their haversacks with soap, and then again in clean water to which a sprinkling of disinfectants had been added, after which they were dried in the sun. In this wise the food we carried with us—for instance, bits of meat saved from one meal to another—kept sweet and good much longer than in the case of men who had not washed their haversacks. If you carry meat about it is advisable to keep the sack or pouch, or whatever receptacle it is, open, except when it rains.

During the march my brother officers of the same company and myself had laid down a rule which we enforced with inexorable rigour: we did not allow stragglers. Show every consideration and indulgence to a man who is weak and faint, relieve him of his burden, let him be supported, give him a stretch on a cart, but let him not lag behind. There is nothing more degrading and demoralizing than a draggletail of weary stragglers. I know of more than one case where men thrust away their rifles in fits of despondency, and, afraid to rejoin rifleless, became deserters, marauders, desperadoes, and even spies. The throwing away of the rifle should be branded as a most heinous offence, and should be anathematized with dire pains and penalties.

A feature which I found to be of great cheer and comfort to the men was well managed by those who had the command during that march. The halting places for cooking and sleeping were invariably well chosen, that is, with a view: firstly, to shelter from the prevalent wind; secondly, to comfort (level, dry, and soft ground, plenty of grass, ferns and shrubs for making beds and for firewood); and, lastly—incongruous as this may sound—to pleasing the eye. For love of nature is inborn in man, and the lowest, the weakest, the most ignorant, the most degraded is impressed, softened, or buoyed up when his tent is pitched among lovely surroundings. After an exhausting march along a barren and dreary high road, an hour's dinner rest on a fertile plateau, "with verdure clad," is a lotion immeasurably better than any ever devised by the most cunning physician. And it is worth while to go out of your way to find such a place, at least so we discovered it to be during the crossing of the Balkans, when we used to leave the cold, damp, cheerless pass by a detour of a mile or more, to pitch camp on a lovely spot amid the adjoining forest solitude, where the wild grandeur of virgin scenery came home to even the coarse and the callous, where the mysterious murmuring of the woods silenced the most inveterate grumbler, and the fragrance of moss and heather braced up the most knock-knee'd weakling. The men will feel grateful, will be genuinely refreshed, and will probably never know that they have gone out of their way. A white lie in time saves many a disagreeable truth. The increase of speed will compensate for time lost.

I come now to the march from Widdin to Plevna in July—Osman Pasha's world-famed performance. This was a far more serious affair; the heat was intense and uninterrupted, even the welcome coolness of night being sad to seek; the journey lay through barren and well-nigh waterless country, and the speed was much greater—115 miles in 7 days, or 16 miles a day.

The Russians had crossed the Danube, and Sistova had fallen. A man whose name is honourably known to all of you, Mr. Archibald Forbes, of *Daily News* fame, has assured me that he possesses proof positive that Sistova fell through treachery. Abdul Kerim Pasha was the man who sold his country. He made a stipulation that, for the sake of appearance, a certain number of Russians—I forget the exact figure—should come to grief in the crossing, and this condition was carried out literally.

The invasion of Bulgaria commenced. Nikopoli fell, and the Russians made southwards towards the nearest town, which happened to be Plevna. In the meantime Osman Pasha, bound to Widdin with his magnificent army for nearly three months by that body of sluggards, cowards, and traitors at Stamboul—those stay-at-home, pen-and-ink heroes, misnamed the council of war—had at last received the sanction to make an offensive movement eastward, after having repeatedly and urgently asked leave for weeks past. He started for Nikopoli, but, not being in time to save it, made for the nearest larger town, Plevna. Thus the situation resolved itself into a race for Plevna, which the Turks won by a short head, that is, by a few hours. Here the collision took place, known as the first battle of Plevna, which was thus on both sides an unexpected encounter, an "extra-turn" not announced on the programme. All the greater and more painful was the surprise to the Russians when it resulted for them in a serious reverse.

That awful march from Widdin to Plevna lives in my memory like a hideous nightmare. The stragglers became so numerous that all good resolutions had to be thrown to the winds. Stage by stage, as we dragged ourselves along, dead-beat, through a country from which all hues had departed before that frightful fine gray dust, distressing news reached us in rapidly successive waves. Biéla and Tirnova taken, the Balkans crossed—we could hardly believe it. The sun shone mercilessly, with an almost deadly effect on brain and eyes, but the shadows lay deep and dark on the face of our chief; for the country was in its death agonies, and to him and to us evolved the sacred task of saving it from the ruthless invader.

There are a few features of this march which I would present to you.

Firstly.—I found out for the first time the value of chocolate, of which I, acting upon competent advice, had purchased a goodly quantity in Widdin. It is digestive and highly nutritious, and has great staying power. I speak, of course, of eating chocolate, not of the beverage. After serious exhaustion, a piece slowly crunched will induce sleep. If it be unsweetened its bitterness is a good temporary thirst-quencher. I do not know whether our manufacturers make unsweetened chocolate; if not, I presume they could be induced to do so. The addition of sugar makes it heating to the body, and is, therefore, to be avoided. I hope the time will not be far distant when a pound or two of unsweetened chocolate will be part of every soldier's outfit on the march. In the German army, so I understand, this plan has already been tried and adopted with good results.

Secondly.—I need hardly point out to you the great value of music when on the tramp. In this respect the Turks failed; for we had no bands. But even the beat of the massed drums gives a tremendous impetus to tired legs. Therefore, do not spare your musicians on such occasions; improvise bands if you have none, and make the men sing. Some drums, a bugle or two, a tin whistle, and even a few copper cooking vessels, will have astonishing results.

Thirdly.—A young regimental officer will do well in such circumstances to make a liberal use of the "gab." A timely joke, a stirring exhortation, a little glib chatter, even a song, will work wonders with exhausted and grumbling men.

Fourthly.—I draw your attention to the plan adopted by Osman of sending cooking parties in advance of the main column, so that the latter, on arriving at pre-arranged spots, found a hot meal waiting. Similarly, tubs were filled in the streams, sent on in advance, and deposited in waterless places.

Lastly.—Credit is due to Atouf Pasha, who had been in possession of Plevna with three battalions ten days previous to Osman's arrival, and, being apprised of his approach, prepared everything for his reception, even to the detail of having a hot meal and a screw of tobacco waiting for each man, with an additional cup of coffee for the officers. That tobacco caused us to forget the atrocious hardships of the march, and the anxiety for the threatened encounter on the dreaded morrow.

I come now to the first battle of Plevna, 20th July. It is the least interesting of the four Plevna actions, and my battalion played but a subordinate part in it. But it was my first appearance under fire, and I recall vividly the terrible strain on the nerves while, in our position among the shrubs of a little valley, we waited for the enemy to appear. Almost the first bullet which whistled past my ear brought on an attack of indisposition, and for a few moments I confess I was fluttered and frightened. I was 18 years old, and fond of life, which had been very beautiful to me, and I was loth to quit it. But the feeling of terror changed quickly to one of the most intense excitement as the fire became vehement on both sides, and only the width and depth of a little ravine separated me from the enemy's skirmishers. I have never experienced such excitement before or since; it almost seemed as if my throbbing heart would rend my breast asunder and jump out—but I had got rid of the feeling of fear. On the contrary; as I passed up and down my line, exhorting, swearing, praying, and talking much nonsensical rubbish, I alone upright, all my men kneeling or lying down, and as I saw *them* struck, saw the bullets hitting the branches, and both heard and felt them passing my head apparently within a few inches, whilst I myself received not a scratch, I was seized by a feeling which I can only describe as a sense of security and invulnerability. I felt an intense vitality burning within me, as if I could be made to fly merely by an effort of the will; my body seemed to have lost its weight, and my muscles to have increased a hundred-fold in power.

The subtle force known as vitality is as much a mystery in our enlightened times as it was in periods of barbarous darkness. Who is competent to deal with such occult questions as the causes of the rise and the fall of vitality in given circumstances? I, certainly, am not; but I can testify to the fact that my life was hottest, the current of my blood swiftest, and the consciousness, I might almost say the insolence, of strength greatest, on the battle-field.

The first battle of Plevna has been the subject of much controversy. The Russian writers—I mean all those writing from the Russian point of view—have affirmed that the Turks fought from heavily entrenched positions.

This is quite untrue. The first battle of Plevna was fought throughout in the open. I think that a simple argument will prove the Russian contention to be a fallacy.

The Russians claim to have been confronted all along the line Grivitza—Bukova (four miles) by entrenchments and works of a solid, elaborate, and permanent nature. But I would ask: "Who made these entrenchments?" The main body of Osman's army had arrived between 9 a.m. and 2 p.m. on the previous day, say, approximately, about noon, dead-beat, after a seven days forced march in the scorching July heat, across a land which was at that season practically a desert; eighteen hours later the battle was fought. Tools were so scarce that even three days after the action the men still used their bayonets and side-arms for digging purposes. It is not at all likely that, under such circumstances, we could have constructed a complete system of fortifications extending over many miles, such as the Russians claim to have encountered in their assaults. I have exceptionally keen eyes; I could overlook the country for miles around, and on my battalion's withdrawal to Bukova I traversed the entire length of the line which the Russians mention specially as having been fortified; yet I saw no entrenchments. It may be argued that Atouf Pasha had those entrenchments constructed by his three battalions in view of the approach of Osman's army. But it is not likely that a capable, clever, and purposeful man like Atouf should have committed such a grave mistake as to construct fortifications which would necessarily have to remain unoccupied for several days, and might at any moment be seized and utilized by the enemy, whom he knew to be in proximity and approaching.

To this topic I shall attach a double advice to company officers entrusted with the task of improvising fortifications for their troops.

Firstly.—Never erect more works than you can conveniently man and hold.

Secondly.—Construct your works so that their backs cannot be utilized by the enemy as fronts.

I would here remind you that no Turkish earthworks existed, and the camp at Plevna had not been formed. My station was on the north front of our position, by a coincidence quite near to the spot on which afterwards my redoubt stood. The Russian attack was four-fold: from the north, the north-east, the south-east, and the south; but in the north and the south, where the Russians had only cavalry available, no fighting took place. In the north-eastern attack, Bukova became the centre of the conflict, from which the Russians were finally driven; and if they did not actually fly, they seemed to me—who was close enough to see them—to be in a desperate hurry to get away. In the south-eastern attack the Russians were temporarily successful, but Osman's threat to have his men shelled by their own guns if they did not make an immediate stand had the desired effect. In the end the Russians retreated on all points, and Plevna was henceforth marked as the centre around which a desperate and prolonged struggle was to be fought. The town became—as it often happens—a factor of fictitious value; it grew a point of honour for Russia to conquer, for Turkey to hold it.

I pass now to the second battle of Plevna—31st July. The Russians had failed with a division in the first attack; two corps (or almost the whole of four divisions), outnumbering the Turks by nearly two to one in men and three to one in guns, were instructed to possess themselves of Plevna at any cost. The result was a murderous battle, fought by both sides with admirable bravery, and ending in one of the worst defeats which the Russian army has ever sustained.

In the ten days which intervened between the first and second battles, a part of the camp of Plevna had been constructed. My station was in the central redoubt on the Janik Bair. There was again a four-fold attack, as in the first battle, and nearly in the same direction. Against my redoubt a treble attack was directed, which was repulsed each time. The Russians got right to the slope of the parapet, and the result was a terrible confusion.

I might say a word as to the dreary and unnerving waiting for the enemy, which lasted from early morning until the afternoon. I found that it was absolutely necessary to give the men some occupation, and this was done by getting them to refill the water-casks and the biscuit-boxes placed in the trenches and the redoubt, and to repair the trifling damage done to the earthworks by the shells. The same plan was adopted in the anxious intervals between the Russian attacks. I should strongly advise that in all such cases some occupation be found for the men; it prevents grumbling and uneasiness, relieves the strain on the nerves, and helps the dreary hours to pass more quickly. If there is really nothing to do, improvise something, and give it an appearance of vital importance.

After the first assault of the Russians had been repulsed, myself, my brother officers, and all the men climbed on the parapet, as if by common consent, and I feel certain that a counter-attack at that moment would have had a decided result, and have prevented the two subsequent attacks of the enemy. However, we were called back. This brings me to the subject of counter-attacks, and I wish to say a word on these, always requesting you to remember that I speak from practise and experience, not from theory or book-learning.

In all the Turkish dispositions for battle the line of retreat was clearly indicated, and for this action the directions were quite elaborate. But we had received no instructions for counter-attacks, in consequence of which none were undertaken, although the opportunity was of the most favourable kind. For a counter-attack to succeed, I should recommend that the following three conditions be complied with :--

(1). Full instructions as to direction should be given beforehand to each battalion and company commander.

(2). It should be undertaken with the whole or nearly the whole force available.

(3). It should be undertaken at once, that is, immediately after the repulse of the enemy's assaults, or, in any case, as soon as the necessary order and cohesion have been restored.

In the flush of victory men are anxious to go forward, would, in fact, if left alone, do so almost without knowing it, and they will have the advantage of running against an enemy whose back is practically, and sometimes actually, turned on them.

With us the circumstances were almost ideal. Every condition of success existed. We were in a fixed position, we expected to be attacked, and had made all preparations. For a counter-attack elaborate plans could have been devised beforehand, and complete instructions given. If, after the first Russian charge, the whole of the occupants of the two redoubts on the Janik Bair (four battalions) had rushed forward immediately, on a line already laid down, the Russians would never again have rallied on this part of the field—that is my firm conviction.

A few words of advice to subordinate officers in a counter-attack, a charge, or any sudden forward movement.

Firstly.—See that all your men who are within easy hail start. To ensure this I found it always advisable to be, for a few moments, slightly behind the line just at the start—that is the time when timid and faint-hearted men are most likely to drop out. But when the rush has fairly set in men are pushed along in spite of themselves; then your station is in front of the line, and then even a single lieutenant of spirit may do wonders, working—as it were—as a propellor to whole companies. The influence of one brave man in such moments is tremendous, and there is no more danger for one slightly in advance of the line than for those in the front line.

Secondly.—I have said advisedly see that all men *within easy hail* participate in the start. By that I mean, do not waste precious moments in searching for missing men. On the battlefield single minutes will often turn the scale.

Thirdly.—If you perceive any strangers, singly or in bodies, walking about disconsolately in search of their officers or their companies, do not hesitate to incorporate them forthwith in your lines—not by way of entreaty, but by way of command. The former they would probably ignore; by the latter they will be impressed.

Fourthly.—There are in all communities men who unconsciously rise above the level of the average, and become guides and mentors to others. You will find maybe only two or three, maybe ten or fifteen, of such men in your company. Keep them close to your person. Have your bugler and your drummers close to your elbows, and do not spare the latter. If your company or section have charge of the colours, keep a constantly watchful eye on these, and let them always be close at hand.

In the second battle my captain was disabled, and my senior lieutenant killed; henceforth, and until the end of the campaign—with one week's interruption—I had command of my company.

Six weeks were then spent in virtual inactivity by both sides, broken only by some fighting around Lovdcha, and by Osman's futile sortie in the direction of Pelishat on the 31st August. By the time the third battle of Plevna—11th and 12th September—was fought a number of additional fortifications had been erected around the camp.

This battle was ushered in by a four days' shelling of great violence, the effect of which, on the Turks, moral and material, was *nil*. I would draw your attention to the wisdom of repairing at night all damage done during the day, and of having, for each redoubt or unit of fortification, a complete and thoroughly equipped workmen's party. There should also be a water party, an ambulance party, and a cooking party to each unit, so as to render it independent and self-supporting. A piece of advice to regimental officers: Regulate your watches to a uniform time, and never omit to state, on every written communication, not only day and date, but also hour and minute. Cause a name to be given to each work or redoubt, and also to external objects, such as houses, streams, hills, meadows.

In the third battle the Russians, now reinforced by the Roumanian army, outnumbered the Turks by three to one in men, and six to one in guns. Yet, despite this terrific superiority, the action was a dismal failure for them; and down to the present day the Turks boast of it as one of the most brilliant victories ever won by the Armies of the Crescent.

The Russian attack was three-fold: against the Grivitza redoubts in the north-east, against Omer Tabiya in the south-east, and against the redoubts south of Plevna. The first-named attack delivered one of the Grivitza redoubts into the hands of the Roumanians; the second failed completely; in the south Skobeleff took two redoubts on the 11th, but was dislodged on the following day. My battalion was withdrawn early from its redoubt proper and sent to the south, and I participated in all the fights against Skobeleff.

A night of terror intervened between the field days, and for such an emergency I should like to make a suggestion. Get your men to be *amused;* when it is necessary to keep them awake commands will be ineffectual with dead-beat men; but amusement and recreation will work it. The Turks are immoderately fond of recitals and stories; and I found recitations—sentimental or humorous—to have a wonderfully rousing influence on drooping spirits, even among the horrors that surrounded us.

The third battle of Plevna is one of the most sanguinary actions of modern times, the total of casualties amounting to close on 25,000, or one-fifth of the forces engaged.

The next stage in my narrative is the investment of Plevna, which was completed by the Russians on the 24th October—in conformity with the advice of Todleben, whom, after the third battle, they had called in to be the saviour of their military honour and political prestige, and ended with the last sortie, on the 10th December. During this period the camp of Plevna reached its greatest extension. These points should be remembered in this phase of the defence:—

(1). The Turks, also, had completed the circle around Plevna by fortifying the hitherto unprotected west front.

(2). They had now in many places a double line of redoubts; and

(3). There was no village or hamlet within the camp, all accumulations of dwellings, except, of course, the town itself, being purposely left outside; even those which naturally belonged to the camp, for instance, Opanetz and Bukova. The reason is clear; these villages, with their dual population, would have constituted a grave danger if within the lines. Where the tendency of the population is hostile, or even doubtful, this plan is to be recommended.

We were now cut off from the world and dependent upon what we had within the lines; for succour and supplies from without, however confidently expected and faithfully promised, never reached us.

A chain is as strong as its weakest link, or, to apply this to our subject, if only one article among the hundreds that constitute human need is missing, or even running short within the precincts of a beleaguered camp or city, the result is always danger, and often disaster and collapse. The gross articles, such as grain, cattle, cloth, and so forth, will not be easily overlooked by those who have the task of organizing supplies in view of a threatened investment; in the smaller things they often fail. Take, for instance, soap, insect powder, sugar, vinegar, candles, matches, lamp oil, firewood, stationery, string, nails, chloroform, and scores of other articles that we, living in the land of plenty, never bestow a second's thought on. Imagine what the position of 50,000 human beings would be if only one of these things is missing!

Major Mayne, in a recent lecture, has enumerated salt among the luxuries. With this I respectfully disagree. Salt is a necessary, if ever there was one, as we found to our cost in Plevna camp, where this article ran short. Also sugar and tobacco I should be inclined to take away from the list of luxuries, and stamp them, if not as necessaries, in any case as things that are highly desirable.

We suffered most from the scarcity of salt, firewood, boots, and chloroform; but, of course, towards the end of the investment, when meat was absent and bread ran short, these considerations were drowned in the one common care for our daily bread. The fervour with which I uttered almost hourly the most pregnant, as it is the most laconic, prayer ever prescribed by any creed, makes me smile in these latter days of scepticism.

On our sufferings I shall not dwell. The winter was exceptionally severe, the weather execrable throughout; we were ragged and starving; hideous diseases raged unchecked—the mortality was appalling. Our position was hopeless. That explains all.

I beg leave to make a few recommendations to those who may find themselves in a beleaguered camp.

(1). Never throw away anything, however trifling or paltry. Pieces of paper, ends of string, rags, bits of straw, used matches, a few inches of thread or twine, nails, screws, odd ends of wood, everything ought to be preserved and will be found useful, and even invaluable, by-and-bye. In circumstances where nothing can be replaced or renewed, this plan needs hardly any commendation.

(2). Do not barter. There is nothing more disgusting and demoralizing than the spectacle of haggling for sordid consideration in times of common need. Right-minded men will despise and abhor anyone who, for instance, sells his rations or his garments. Lay aside for once in a while the awful worship of money, the vice of hoarding, which has made this earth and this race what they are; which has prostituted human life down to the level which we behold at every hour of our existence, with every step that we take abroad.

(3). Be firm and just towards your men, but forget the difference of class and birth. Every trifling service rendered to one, however much below you, will repay itself, sometimes a score-fold, in the fulness of time.

(4). Let your men work at their trades, so that the highest possible efficiency may be got out of every community or unit; for instance, out of the company. The cobbler, the tailor, the mechanic, the barber, the carpenter, occupy each man in whatever he may be most proficient, so that, as far as possible, your company renders itself independent of others. It will raise the reputation of your troop.

(5). Dispense freely the hospitality of your redoubt, or camp, or bivouac, to any such comrades from other sections as may visit you.

(6). The—under such circumstances—frequent offence of stealing victuals should be punished with the utmost severity. In the

American North Polar Expedition of 1882 a man was shot for stealing a trifle of alcohol reserved for medicinal purposes.

Lastly, if there are women dwelling within the camp boundaries, and they are willing and amicable, do not hesitate to make them work, at womanly pursuits only, of course, such as mending garments, cooking, nursing the sick. It has a wonderful elevating influence on hordes of men—brutalized, perchance, by months of warfare—to see even a few women actively espousing their cause.

I come now to the concluding part of my subject, the last sortie, on December 10th. Betrayed by his country, forsaken by all the world, abandoned to his fate by God and man, Osman Pasha, unlike Bazaine, declined to surrender tamely in his trenches, and decided, with the unanimous consent of the council of war called by him, to strike one last fierce and desperate blow for liberty.

All the redoubts of the eastern semi-circle were abandoned, and the direction of the sortie was north-west, following the line of the Rahova high road.

I lack the time to dwell upon our preparations, which were of the most thorough and methodical description, notwithstanding the pregnant misery of our position, the unutterable horrors behind and beside us, the prospect of worse to follow. I would advise a study, map in hand, of Osman's *ordre du jour*, which is reproduced in my volume.

There is the faculty given to every man to rise in the hour of need to the sublime height of manhood, which is Godhead. And of a surety, if ever men did ascend to that lofty height, where, to quote Schiller, "they stood nearer than ever before to the soul of the universe," those men were Osman Pasha's ragged, weather-beaten, starving Tartar heroes. It was worth while to have lived and suffered to see our first division form for attack in the cold grey dawn of that dismal, and yet so glorious winter morning; to have heard the great shout of "No surrender!" which went up into the dim, snow-pregnant heavens, as the huge column was set in motion towards the appointed goal of that stupendous struggle, freedom; to have listened, rapturously, to the prayer "In the name of the Merciful God," which kept pace with the step of the charging brigades and led us right amid the enemy's batteries. If I had then fallen, as scores upon scores of men fell beside me, my death would have yielded no excuse for lament on the part of surviving friends, for I had witnessed that which was divine: moments of such overwhelming grandeur as no words can describe, and not the most cunning pen or pencil can paint.

You know the result of that sortie: first the flush of victory, quickly dispelled; then retreat before a hostile counter-attack delivered with a stifling superiority of numbers; then a last and desperate stand, and finally unconditional capitulation.

I have now finished with my subject, and can justify the superficial nature of my remarks only by the limit of time set to me.

In conclusion, I wish to say a word of advice to the younger of you, who have not yet had the good fortune to smell powder in grim earnest. The moment may come when the call will be made on you to leave the friendly shelter of the ditch or the low earth knoll, to rush forward once more across fields on which death and devastation reign supreme. In such moments *one* must be the first, and, give a first, hundreds of seconds will be found to follow. That to be the first requires an enormous effort of the will not the bravest will deny. It demands of you the exertion to the utmost of all that is best, strongest, greatest in your mental constitution. My advice to you is: imagine that none else is likely to be the first—though this will probably be far from true—and that it is your sacred task, your personal task, to take the lead. If every officer were to practice this innocent self-deception, then never on the battlefield would the command "Forward" be given in vain; then you would win your battle, for it is as difficult to stem the rush of determined men as it is to dam the swell of the incoming tide. Hoenig, whom I have mentioned before, has uttered these remarkable words, which one would do well to ponder over, for they are an apparent paradox, and which I should like to see affixed as a text to the wall of every messroom in England:—"The resolution to die constitutes that moment of a human life when vitality rises to its highest perfection."

The battlefield makes call upon a man for all there is great in him—physical, intellectual, and moral. If a given cause be worth fighting at all, it is worth fighting well; and to do so one has to throw into the scale the best and utmost powers of mind and body, the concentrated essence of accumulated knowledge and experience, the joy of living and the readiness to die. Without the state of being prepared to stake and sacrifice everything—life and limb, and the powers of mind and brain—a soldier can never lay claim to that word. Körner, the famous German singer of liberty, who himself fell fighting in the cause of Europe against the first Napoleon, uttered these golden words:—

> "He that would grasp the crown of this fair earth
> Must stake his all, and be prepared to lose it."

Should you ever be called upon to fight, I sincerely trust that it will be for a cause which every man, from the Field-Marshal down to the drummer-boy, may conscientiously regard as righteous; for, all said and done, that is the most powerful factor in warfare.

PAPER III.

FLAT-BOTTOMED BOATS.

BY LIEUT. W. A. WATTS-JONES, R.E.

THE flat-bottomed boat of Northern India is remarkable for the ease and speed with which it can be built out of very poor materials, and for the comparative ease with which it can be handled in the swift shallow rivers of the country.

The dimensions of the boats are as follows :—

Length over all	60 feet	to	25 feet.
Extreme beam	20	,,	8 ,,
Depth of hull	5	,,	2½ ,,
Draught loaded	2½	,,	1 ,,

I believe larger boats are built in the same way, but 60 feet is the longest I have ever seen.

The boats I had most to do with were about 40 feet long over all, 15 feet extreme beam, 12 feet width at bottom, 3 feet depth inside, and drew 2 feet of water when loaded. These boats, in bridge, supported a 5-ton portable engine, the bridge being such that all the load could come into one boat. As ferry boats they carry as many people as can get into them. The maximum load they will carry is about eight tons. The materials required for such a boat are :—

One-inch or ¾-inch planking, the longer the better, but no piece *need* be over 10 feet, and pieces down to 4 feet can be worked in.

Six or seven beams, about $16' \times 8'' \times 5''$. If square timber is not available, round poles can be, and often are, used.

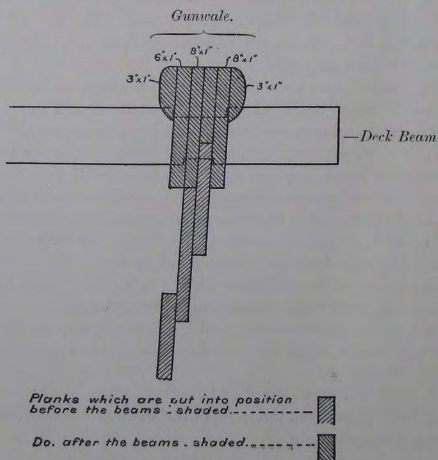
A quantity of 4-inch iron nails. (Pegs might possibly be used for the bottom and sides, but at the curve at the ends would probably work loose).

A quantity, about 2 cwt., of caulking fibre.

A fibre made from the roots of the dhák tree is used, as it is cheap, but anything will do.

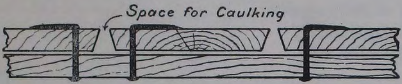
The method of construction is as follows :—

A piece of ground, about $60' \times 30''$, on the banks of the river, is levelled and smoothed. On the ground is laid a layer of 1-inch planking, the length of the planks being across the boat. On this is laid another layer of planking, at right angles to it, *i.e.*, with the length of the planks *along* the boat. These two layers are then nailed together with two nails in each intersection ; the nails project 2 inches or so into the ground. The whole thing is turned over, and the nails clinched by simply bending over and hammering down. This forms a mat of planks, flexible, but strong in both directions. This mat is then cut to the shape of the bottom of the boat, and a piece about $4'' \times \frac{3}{4}''$ nailed all along the edge of it. It is then bent to the curve required by supporting it at the two ends, and piling wet earth on the centre, under which it gradually sinks. The duration of this process depends on the thickness of the outer (longitudinal) layer of planking. It should not be hurried too much. With 1-inch sal planking it took about four days. When the bottom has sunk to its proper curve most of the earth is taken off, and the sides are put on, beginning from the bottom and using clinker build. When the sides are up to the full height the gunwale and beams are put on.



The method of putting on the gunwale and beams can best be understood from the above sketch. The beams are about 4 feet apart.

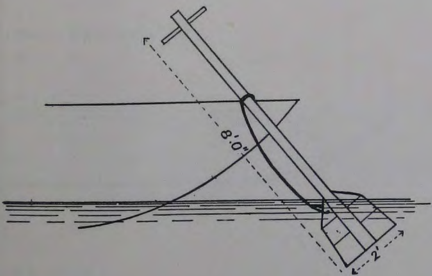
The inner layer only is caulked, and the caulking is done from the inside, the planks having been bevelled off before being put into the boat so as to hold the caulking firmly. Ribs, down the sides only, are then put in.



Part Longitudinal Section.

The boat is then launched.

The next thing to be done is to strut *down* the bottom of the boat from the deck beams. It is most important to do this properly, as the only part of the boat which is at all stiff is the deck-beams and gunwale. The method of strutting is shown in the drawing. The principle is, of course, to allow as much "give" as possible, and at the same time make each bit of the bottom carry the same load. The boat is then decked, and is complete for ferry, bridge or flying bridge work. It is steered by a large broad-bladed oar lashed on to the stern thus :—



The method of working is highly ingenious, but applies, perhaps, too exclusively to the Indian rivers to be of general interest.

As regards the plate :—

Fig. 1 shows the boat I have described.

Fig. 2 is a modification of the same boat ; it worked better, but is rather more difficult to build.

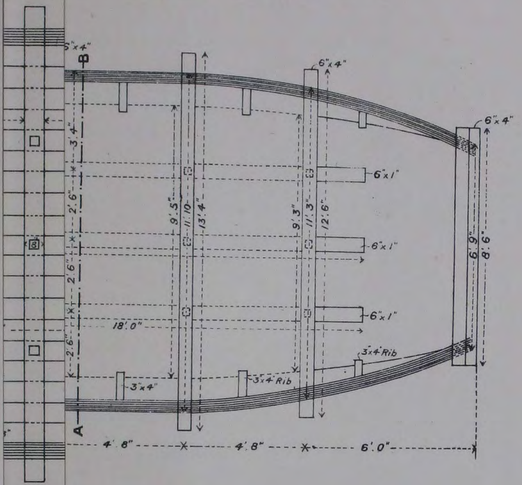
The usual time taken to build a boat was ten days to two weeks. It can be built in a week if necessary.

Labour required—

1 skilled carpenter.
2 carpenters.
2 coolies.

FIG. IG. 2.

DPTEUR TIGRI AND AGWANPUR
AD ES MORADABAD.



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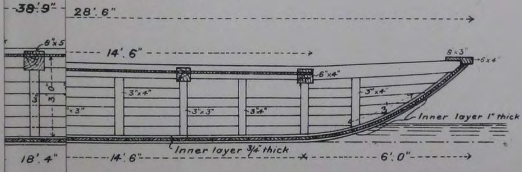

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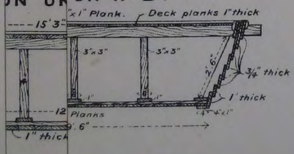


PAPER IV.

NOTES ON SUSPENSION BRIDGES ON THE ROAD FROM KASHMIR TO GILGIT.

By Captain J. E. Capper, R.E.

General.—Having had within the last three years several suspension bridges of various kinds to erect, it has occurred to me that the experience may be of use to others who are called on to erect similar bridges with as little knowledge of how to set about it as I had at starting. The bridges are on the road between Bandipur, in the Kashmir Valley, and Gilgit, which is now garrisoned by a considerable body of native troops.

Gilgit Road.—The road is a mountain road 10 feet wide, with maximum grade of 1 in 10 nominally, but in places the grade is as steep as 1 in 6½. It is, therefore, only suitable for pack animals, of which some 12,000 to 15,000 are employed yearly, making from one to three trips in the summer, to supply provisions for the various posts in the Gilgit district.

Bridges.—The suspension bridges erected on the road are:—

(1). The Purtap bridge (called after H.H. the Maharaja of Kashmir), over the Indus river, near Bunji, span 337 feet, width of roadway 10 feet (*Plate* I.).

(2). The Ramghat bridge, over the Astor river, at Ramghat, span 171 feet, width of roadway 7 feet (*Plate* II.).

(3). The Garikot bridge, over the Astor river, at Garikot, one span 162 feet, one span 81 feet, width of roadway 7 feet (*Plate* II.).

Each of these bridges presents special features which I think are worthy of note. I also purpose to add a short note on light suspension bridges for military purposes, as in many cases these are the only form of bridges which can be put up quickly in a country where material is scarce.

Purtap Bridge.

The Purtap bridge is the most important bridge on the road, as it is of a semi-permanent character. It is not altogether satisfactory, as the design had to be altered completely at short notice. It was originally intended to erect a bridge with ten $4\frac{1}{2}$-inch circumference steel wire ropes on either side, with suspension rods of steel, and the whole of the bridge-way, with the exception of the longitudinals and planking, of iron. There were to be four $4\frac{1}{2}$-inch circumference steel wire ropes on either side as wind ties. The bridge was made in England by Messrs. Bullivant & Co. Having been ordered up to the Gilgit road especially in order to erect these bridges, it was disappointing to find on my arrival in Kashmir, in August, 1891, that a large portion of the bridge material was still at the coast, delayed by breaks on the North Western Railway, whilst nothing had been done for the Garikot and Ramghat bridges. Fortunately, the anchorage girders and the ropes had arrived, and were being carried up to the site under arrangements made by Captain Yielding, D.S.O., the officer in charge of the Gilgit transport.

Transport of Material.—The transport of the material was a matter of great difficulty. The distance from Bandipur, where the mountain road begins, to the site of the Purtap bridge is 164 miles. The road is only 10 feet wide, was in parts unfinished, and in places there are nasty zigzags. Some of the bridges were also still in hand, and some of these, over the broader streams, were only native bridges, quite unsuitable for carrying heavy weights. The total weight to be carried up was only about 45 tons, but the loads were clumsy in the extreme, though none except the ropes themselves weighed over 4 to 5cwt. The 20 main ropes were 560 feet long, and weighed about 21cwt. each. The eight wind tie ropes were 460 feet long, and weighed about $17\frac{1}{2}$cwt. each. They were Bullivants' patent flexible ropes, consisting each of seven $1\frac{1}{2}$-inch circumference steel ropes, each of these being made up of 19 strands of fine steel wire. If the ropes had been stiff, the difficulties of carriage would have been enormously increased.

The method adopted was to double the ropes, tying them together at intervals. A squad of coolies was then placed along the rope, the number being arranged so as to give each man a weight of about 40lbs., and the rope was lifted on their shoulders. The men employed were not a good class for the work, being unaccustomed to carry weights except on their backs, and were got along with difficulty. The weather was bad, but no delay could be permitted, as the passes would probably be closed by October, and two trips had to be made between the first week in August and October. Great credit is due to the transport officials for having succeeded in getting up the material under very adverse circumstances.

Design of the Bridge.—Under the circumstances, as it was obviously out of the question to get up the material, which had not even in August reached Kashmir, a change of design was necessitated, and a wooden bridge of a much lighter form was substituted. This would allow of some of the ropes being utilized for other bridges, of which many were required in the country, though the Indus bridge would, of course, become of a more temporary nature.

The bridge was designed as shown in the drawings attached (*Plate* I.), the wood being pine, as no deodar is procurable in the district. It will be seen that the main features of the bridge are :—

(1). Iron anchorages.
(2). A number of $4\frac{1}{2}$-inch wire ropes on either side.
(3). Suspension wires instead of rods, at 9-foot intervals.
(4). A wooden vertical girder with iron tie rods.
(5). A wooden horizontal girder with iron tie rods.

After determining the style of the bridge, it was necessary to calculate the strength of the various parts. To find the number of ropes required, the dip of the rope was first fixed on. It was made $\frac{1}{12}$ of the span. The strain on the ropes at the points of support, *i.e.*, at the saddles, is found from the formulæ

$$S = \frac{CL}{8V},$$

$$s' = S\sqrt{\left(\frac{4V}{C}\right)^2 + 1},$$

where S = strain at centre of bridge in tons.
C = span of bridge in feet.
L = total load in tons, including weight of bridge.
V = dip in feet, *i.e.*, vertical distance of centre of rope below points of support.
s' = strain at point of support in tons.

For a dip of $\frac{1}{12}$ span,

$$V = \frac{C}{12},$$

and
$$S = \frac{12CL}{8C} = 1\tfrac{1}{2} \times L,$$

$$s' = \frac{3L}{2}\sqrt{\left(\frac{4C}{12C}\right)^2 + 1} = \frac{3L}{2} \times \frac{\sqrt{10}}{3} = L \times 1{\cdot}581.$$

Therefore s' may, for all practical purposes, be taken as $= 1\frac{1}{2} \times L$.

The maximum weight to be brought on the bridge was calculated to be 1 cwt. per square foot, inclusive of weight of bridge, and this should be ample, as it is unlikely that this will be approximated even at extraordinary times, whilst the general traffic over the bridge brings but little strain on it.

The total load allowed for (the bridge being 327 feet in clear between faces of masonry supports) is $163\frac{1}{2}$ tons, making a strain at point of support of $163\frac{1}{2} + 81\frac{1}{2} = 245$ tons.

The breaking weight of one of the main ropes is about 72 tons—allowing a factor of safety of 3—the safe strain on one rope is 24 tons. Therefore 10 ropes, five on each side, are sufficient for safety.

It was decided to put the suspension wires 9 feet apart. The weight on each cross-beam to be allowed for is, therefore, $9 \times \frac{1}{2} = 4\frac{1}{2}$ tons, and on each suspension wire $4\frac{1}{2} \div 2 = 2\frac{1}{4}$ tons. The points of support of the cross-beams are 11 feet apart. The size required is found from the formula

$$W = \frac{8KBd^2}{L},$$

where W = breaking weight in cwts.

L = span in inches.

K = coefficient = 12 for pine.

B = breadth in inches.

d = depth in inches.

Allowing a factor of safety of 10—

$$W = (10 \times 4\tfrac{1}{2} \times 20) \text{ cwt.}$$
$$= 900 \text{ cwt.},$$
$$L = 11 \times 12;$$

$$\therefore \quad 900 = \frac{8 \times 12bd^2}{12 \times 11};$$

$$\therefore \quad bd^2 = \frac{9900}{8} = 1237;$$

therefore a beam 12″ × 9″ is suitable.

The breaking weight of the main ropes being over 70 tons, that of each of the seven small ropes of which it was composed was assumed to be able to bear a weight of 10 tons. Therefore, a load of $2\frac{1}{4}$ tons could safely be put on these ropes, one of which was very suitable for each suspension wire.

In order to stiffen the roadway from vertical stresses, the hand-rail was made into a vertical girder. It was not calculated for strength, which was a mistake, as the bridge is not so stiff as could be desired.

To stiffen the bridge from oscillation, two precautions were taken:—

(1). The main ropes, which are 20 feet apart at their centres at the points of support, are brought in to 12 feet apart at the centre of the bridge.

(2). A horizontal girder was added, built on the top of the cross-beams, the booms of this girder forming the lower booms of the vertical girders.

Details of the girders are shown in the sketches.

The design of the strutting to the vertical posts is faulty at the upper joint, where, if there is much motion on the bridge, there is a tendency of the two bolts AA to shear through the triangular portion of the filling piece (*Fig.* 1, *Plate* IV.).

BB are bolts fastening the two struts and the filling piece to one another and to the upright.

The design adopted for the other bridges is better in every way (*Fig.* 2, *Plate* IV.).

The other points worthy of mention in the design are:—

(1). Attachment of main ropes to anchorages. This was effected as shown in *Figs.* 3 and 4, *Plate* IV. The clips are very simple. They are a patent of Bullivants, and three clips, each fastened by six bolts, admit of the doubled portion of the rope being so firmly attached to the main rope that the rope will break before it will pull through.

(2). *The Saddles.*—These were also sent out with the bridge. Each consists of a solid steel block curved on the top to take the curve of the rope, with grooves in which each rope was placed. These saddles rested on rollers fixed in a frame firmly secured to the bottom plate, which was held down by holding-down bolts. This was found to be a mistake, and stops had to be fixed to prevent the saddle plate pulling over the rollers, whilst it was found that the ropes move quite as freely as required over the fixed saddles. It is, therefore, sufficient to provide simply a solid block with countersunk holes into which the top of the holding-down bolts can be fixed.

(3). *Attachment of Suspension Wires to Cross-beams.*—This was effected neatly and strongly by the following arrangement:—

About 3 inches of the end of the rope was unstranded, each wire of the 19 composing the rope being separated and drawn as straight as possible. The unstranded end was then passed through a small iron cylinder in which was a conical hole as in *Fig.* 5, *Plate* IV. Each individual wire was then turned over outwards at about 1 inch from the end, and pressed back against the main wire till the end of the rope was of the form shown, the wires being pressed as close together as possible (*Fig.* 6, *Plate* IV.). The end thus formed was drawn back into the hollow cone and driven in as tight as possible. An iron plug was then driven down into the centre to jam the wires tightly outwards, and the whole heated and run in with lead; zinc would have been preferable, but none was available. It was found that under a strain of over 2 tons there was no tendency of the end to pull through.

The free end of the rope was then passed through a $\frac{5}{8}$-inch hole drilled in the cross-beam until the cylinder bore fairly against the latter. The wood at the point of bearing was protected from wear by a piece of $2\frac{1}{2}'' \times \frac{1}{4}''$ iron fixed along the bottom of the beam. Here it would have been preferable, if material had been plentiful, to continue this as a strap right round the beam, both to prevent the beam from splitting at the end, and to save the wear on the wood where the suspension wires come out at the top, these wires towards the centre of the bridge being inclined at a considerable angle to the perpendicular.

(4). *Attachment of Suspension Wires to Main Ropes.*—*Fig.* 7, *Plate* IV., shows the arrangement, the distances between items being exaggerated for the sake of clearness. The ropes are actually as close together as they can be put. and there is only $\frac{1}{8}$-inch play between the ropes and the bolts.

The long length of screw on the supporting bolts was given to allow of adjustment as well as to enable a bottom nut to be put on. With length of wires carefully calculated, it is unnecessary to allow for adjustment. The thimble was made out of $\frac{1}{16}$-inch iron 3 inches internal diameter, and should have been stronger. The rope was wrapped twice round it, and fastened by two double clips as shown, one being found insufficient. The arrangement is somewhat clumsy, but has the advantage of allowing any defective piece being readily made good, the cross-beam being temporarily supported by a block and tackle.

Length of Supporting Wires.—There is no difficulty in determining the length of the suspension wires very accurately, once the dip is decided on, and the distance apart of the wires has been determined. The length of each wire is found from the formula

$$L = \frac{V \times x^2}{(\frac{1}{2}C)^2},$$

where L = height of point of the support of the wire under consideration over the lowest point of the main rope in feet.

V = Total deflection in feet.

x = distance, horizontally, of the point of support from the centre of the bridge in feet.

C = span in feet between centres of saddles.

For a dip of $\frac{1}{12}$ C = 12V, and the formula is simplified into

$$L = \frac{V \times x^2}{(6V)^2} = \frac{x^2}{36V} = \frac{x^2}{3C}.$$

To the length thus found for any individual wire must, of course, be added a constant representing the length of the shortest, *i.e.*, the centre rope of the bridge, and a length varying for each rope to allow of some camber on the bridge.

Camber.—For camber it would appear advisable to make the central 6th part of the bridge level, and run up slopes from the abutments of about 1 in 80. If a parabolic camber is given, the grades near the abutments become very steep, and the slopes are simpler to calculate and answer every practical purpose.

Erection of the Bridge.—Light Wire Rope.—The first step taken towards the erection was to get a light line over the span; to this was then attached a strong log line, by which again a $1\frac{1}{2}$-inch circular steel wire rope was dragged across. This was strained up fairly tight by tackle, and made fast to the anchorages on either side.

Frame over Saddle.—The position of this rope was over the centre of one pair of saddles, and it was carried on a wooden frame (see *Plate* III.). It would be preferable to have the frame strutted from the outside to render it firmer, as shown in *Fig.* 8, *Plate* IV. If made with any stiffening pieces running parallel to the top beam and below the level of the bar, it cannot be removed after the main ropes have been placed in position, and has to be partially destroyed.

Traveller.—On the light wire rope was fixed a traveller. It calls for no special comment, but should be made with one side fastened on by bolts and nuts, so as to be easily fixed on to the rope, and should have adjustable clips below to take the 4½-inch ropes. A short sling can be put into these clips afterwards, from which block and tackle can be suspended. The traveller was attached to the centre of a doubled log line, so as to be readily hauled across the river from either side.

Crossing the Main Ropes.—The main ropes were collected on the left bank of the river, stretched out in order at right angles to the bridge, and one end of each fastened to the anchorage. The free end of the first rope was then brought round, lifted to the top of the abutment, passed over a grooved pulley and fixed into the traveller. Care should be taken to leave about 12 feet of rope end free beyond the traveller, fastening the end in a loop so as to allow of the end being rapidly got at from the far abutment when the traveller reaches there. The object of this free end is to save the shifting of the clip on the main rope when it is required to fasten the far end to its anchorage. With the first rope I got over I met with great delay by neglecting this simple precaution. Meanwhile, one end of the hauling tackle, which consisted of a double and single block with 3-inch manilla rope, had been taken across the river on the traveller. The single block was taken across together with the free end of the tackle, the double block being left on the side from which the main ropes were to be hauled. The free end and the single block were carried through the frame over the saddle plate, so that the falls rode on the grooved pulleys, and the block was made fast to the anchorage. For attaching the tackle to the main rope a special clip was used, of which a drawing is given (see *Plate* III.).

Special Clip.—This clip is so useful and simple that a short description seems advisable. It consists in its simplified form, as shown, of two eccentric levers working on pivots in two iron plates, the whole being loosely joined together by extending the pivots and either setting up the heads or threading them to take a nut. One side at least should be furnished with nuts which should work very freely. The top plate can then be taken off very easily by removing the nuts, the levers moved so as to open the clip, which can then be placed on any part of a rope. The top plate is then replaced, and it will be seen that by drawing the ends of the levers together the rope is clipped. If then a sling is placed through the eyes attached to the end of the levers, which is loose enough to allow of the levers being opened, the hook of a block can be placed in this sling, and by the mere fact of pulling on it the clip grips, and the harder the pull the tighter the grip. By simply slackening off so as to open the clip it works freely, and can be run up or down the rope to any new position required. By using two of these clips in a position where only a short length of rope can be hauled in at a time, one being attached to a tackle, and the other to fixed rope, any length hauled in by the tackle can be gripped by the fixed clip, and the tackle clip can be shifted with very little waste of time. The fixed clip also acts as an excellent precaution in case of any accident occurring to the tackle, as the rope cannot run back, being gripped tight before it gets a fair start to do so.

The object of attaching the tackle to the main rope and not to the traveller is as follows:—The rope has to be hauled across the river to the top of the far abutment, and then back behind the abutment to the anchorage. A glance at *Plate* III., which shows the support for the wire rope on which the traveller runs, will show that the traveller can only go as far as the top of the abutment, and the tackle, if attached to it, would have to be shifted. By attaching it from the first to the rope no shifting of tackle is required.

The general arrangement by which the main ropes were hauled over is shown in sketch (*Plate* III.). The ropes were hauled over without difficulty, care being taken to brake the shore end at the saddle to prevent it running out too quickly. It is necessary to allow a fair amount of slack the river side of the abutment, otherwise the pull becomes severe.

As soon as the traveller reached the far abutment it was lifted on to it and made fast, the main rope was disconnected from the traveller, the loop undone and the end passed over the grooved pulleys, and hauled by the tackle until it had reached the anchorage.

The rope was then lowered into the saddle plates by lifting it each side of the pulley by wooden handspikes and knocking out the 2-inch iron spindle on which the pulleys worked; the rope could then be gently lowered, and the spindle and pulleys re-adjusted ready for the next rope.

The falls of the tackle were then bound with spun yarn to avoid a slip, and the free end of the rope was made fast to the anchorage. No attempt was made to adjust the ropes to the proper level until all were across. When the end was made fast the tackle was slacked off and fastened again to the traveller, which was drawn back, and the second rope hauled across in the same manner. Time can be saved by securing the rope temporarily to any convenient holdfast as soon as the end arrives at the anchorage, the end being still left free, so that the tackle can be taken off and hauled across the river whilst the end of the rope is being securely fastened to the anchorage.

As soon as the five ropes on one side had been taken across, the saddle frames and overhead wire were removed to over the other pair of saddle plates, and the five up-stream ropes were crossed in the same manner.

The labour employed was mostly entirely unskilled, with the exception of five or six men who understood a little about tackle, and the ordinary blacksmiths and carpenters, so progress was slow. The men trained fairly rapidly, as can be seen from the increase of work done each day. Thus, everything being ready the previous evening to haul the first rope across :—

(1). On the first day of hauling only one rope was got across and fixed.

(2). On the second day two ropes were got across and fixed.

(3). On the third day two ropes were got across and fixed, and the overhead wire was shifted.

(4). On the fourth day four ropes were got across and fixed.

(5). On the fifth day the last rope was got across and fixed, all ten ropes were adjusted to proper level, and the overhead wire was shifted to the centre of the abutment.

The increased rapidity was gained partly by the men training into the work, and partly by slight alterations of method, and by the extra rapidity gained by using the simplified clip and a free end to the rope. The method described is that which we were working on when we crossed four ropes in the day, and possibly increased rapidity could be secured by further modifications.

I did not run the risk of trying whether a rope could be hauled over such a long span independently of the overhead wire. If it can be done there would certainly be a gain of time, but I thought there was considerable risk of the end catching in rocks in the bed. For smaller spans I found the overhead wire to be unnecessary for crossing the main ropes, but one should invariably be put across, to simplify the erection of the bridge.

Adjusting the Ropes.—The design of the bridge showed to what level the ropes should be raised in the centre, but it was exceedingly doubtful whether they would stretch when the weight of the bridge came on them, and as a very slight extension of length would affect the dip considerably, this was a matter of moment. Messrs. Bullivant had stated the ropes did not stretch until loaded with a weight bearing some proportion to their breaking weight. I thought it probable, though, that some increase of length would occur, and, therefore, raised the ropes to a level 6 inches higher than the positions they were ultimately intended to occupy. This was pure guess work, but it turned out to be about correct.

The ropes were adjusted one at a time. A clip was fastened to the rope close to the abutment at the point marked X on *Fig.* 9, *Plate* IV., and a tackle consisting of a double and treble block, with $4\frac{1}{2}$-inch manilla rope, was fastened from this to the anchorage, the pull of the tackle being as nearly as could be arranged along the direction of the rope.

The strain having been taken, the main clips at the anchorage were taken off and another light tackle, consisting of a double and single block with 3-inch rope, was fastened from the free end of the rope to the abutment, so as to take any slack that was gained.

A dumpy level had been fixed up reading exactly the height to which it was desired to raise the bottom of the ropes in the centre of the span, and at this level I stayed, signalling the men on the main tackle to haul until the rope was sufficiently raised. The men on the light tackle took the slack round the anchorage block as they gained it, and as soon as the proper level was reached the falls were bound and the main clips securely fastened.

It should be noted that most of the ropes had got badly kinked in places, becoming unravelled, as shown (*Fig.* 10, *Plate* IV.). to a certain extent. We could neither force the strands back, nor pull the kinks out by any available tackle, and I was afraid that trouble would be caused by them ; but when the weight of the bridge came on the ropes the kinks were pulled out without visibly affecting the dip.

Wooden Girder.—The greater portion of the wooden girder was made and fixed up on shore, so as to allow of its being fitted easily. The wood for the whole span could not, however, be obtained in time for this, and a portion had to be fitted and fixed on the bridge itself. Practically, about two-thirds of the bridge was fixed on shore, and each piece was numbered and lettered at each joint to ensure proper fitting. When everything was ready to start erection, it was taken down.

Cross-beams.—The first procedure was to get the cross-beams over. Each was got ready with its suspension wires passed through it, numbered in order from the abutment, and each in turn was launched, beginning from the shore end. The procedure adopted for getting the cross-beams out was as follows :—

(1). A light tackle consisting of two single blocks was attached to a short sling placed in the traveller. The running end was kept on shore, and the loose block hung vertically below the traveller. This block was attached to a sling passing around the cross-beam, so that by hauling on the running end of the tackle the beam could be raised to any desired height. A tackle was also attached to the traveller by which it could be hauled across the river from the far side. There was then no difficulty in hauling the cross-beam to the required position, and lifting it to any requisite height. The sketch (*Fig.* 11, *Plate* IV.) shows the method clearly.

Meanwhile a platform had been placed on the top of the main ropes.

Platform on Main Ropes.—This platform was made of 3-inch planking strengthened at the joints, and was 24 feet long and 2 feet wide. On the top at each end was fitted a rough box without a lid, and below was a strip of wood fixed as a guard to prevent it slipping off the ropes (*Fig.* 12, *Plate* IV.). Two men, fitters with good heads, were sent up on to this platform to attach the suspension clips to the main rope. They were each furnished with a length of about 30 feet of log line, a hammer, spanners to fit the nut of the clips, a 9-foot rod to measure the proper position of the rope from the last suspension wire, and some spun yarn. As a precaution against the platform slipping, a preventive rope was attached to each end and held by two men on the abutment, but this was really unnecessary.

Fixing Suspension Wires to the Main Ropes.—The platform was pushed down by the men on it to just below the position of the first suspension wires, which was accurately measured from the abutment. Each man on the platform then let down one end of his length of log line, which was made fast to the clips of one suspension wire attached to the cross-beam. The beam was then hauled over and lifted to such a height that all strain was taken off the suspension wires when the clips were raised above the level of the ropes. The men on the platform then hauled up their log lines, loosed the nuts and outer bolts off the clips, removed the top plates, and placed the clip roughly in its proper position on the ropes, replaced the top plate and bolts, and replaced the nuts again loosely. The clip could then readily be hammered further along the rope, or back a little to bring it accurately into position before fixing the nuts tight. It would probably ultimately save time with a large bridge of this nature to send men across to mark accurately the position of each clip on the ropes before placing the clips at all, but these distances varying with the slope of the ropes, must be measured on them, and very intelligent men must be available for the purpose. As each cross-beam was slung out, a temporary roadway was made by placing a couple of planks across from one cross-beam to the next, and these were roughly attached by guards underneath, as in *Fig.* 13, *Plate* IV.; if these guards are not fixed, the swaying of the cross-beam will soon result in the planks falling into the water.

Horizontal Girder.—The next proceeding was to place the horizontal girder in position. This was a mere matter of fitting, as by putting a few more planks across a span a convenient platform could be made for the men to work on. The long bars were got into position quite easily by suspending the head from the upper platform whilst the end was brought against the hole in the boom, which had been already drilled (*Fig.* 14, *Plate* IV.).

Attachment of Bridge to Abutment.—On the abutment the wall plate should be fixed to the masonry by holding-down bolts. The horizontal girder can then be fixed down by bolts passing through the wall plate and boom, and by leaving slots in the boom, freedom of longitudinal movement is ensured, whilst the tendency of the end of the bridge to lift from the abutment is counteracted. The sketch (*Fig.* 15, *Plate* IV.) shows the arrangement. Iron roller guards fixed in the masonry and bearing on the top boom of the vertical girder form an additional safeguard against this tendency.

Wind Ties.—As soon as the horizontal girder and longitudinal are in position, wind ties should be attached The wind ties used for the Boonji bridge were two $1\frac{1}{2}$-inch circular steel wire ropes on either side. They were made fast to anchorages in the rocks about 40 feet up and down-stream of the bridge, and worked on rollers attached to the bottom of the cross-beams. These wind ties overlapped at the centre of the bridge thus, as shown in *Fig.* 16, *Plate* IV.

The ties could not be taken down very much below the level of the roadway, owing to the bridge having been made too close to water level, and it was thought dangerous to place the wires too low, where they might possibly be caught by some floating obstruction if the water rose, and tend to wreck the bridge.

I am of opinion that where the ropes are splayed out sufficiently at the abutments, side oscillation is entirely checked, and horizontal wind ties are unnecessary. Suspension bridges are wrecked by wind getting under the platform, lifting it bodily, and then letting it fall; if this continues the bridge is shaken to pieces. A strong vertical girder prevents this motion, but where it forms the handrail it may meet with an accident. It would appear, therefore, that the best position for wind ties is vertically under the bridge, and I would place them in an inverted catenary, fastening them to each of the cross-beams by ropes of sufficient strength, and give the catenary about half the dip of the main span. The most dangerous state of a bridge is when the planking has been laid and the vertical girder has not been fitted; it is, therefore, advisable to lay the planks mostly loose, so that in case of high wind before the completion of the vertical girder planks can be taken off at intervals, leaving safety valves in the platform by which the wind can escape. The winds on the Indus were at times very severe, but with the light wind ties and using this precaution of removing planks when necessary, though there was considerable vertical motion which made working difficult, no material damage occurred to the bridge during construction.

Woodwork.—Unfortunately, only green timber could be procured; there was not a piece of seasoned timber in the country. Green pine timber shrinks when exposed to the sun and dry air to an extraordinary extent, especially when cut up into small scantlings, so the framing of the bridge girders, though originally good, is now indifferent at the joints, and it is necessary to have the bolts continually tightened up. Great inconvenience has also been caused by the longitudinal shrinking of the scantlings. It has been mentioned that a portion of the woodwork was erected on shore, and it was left standing until required for erection, being fitted exactly as it would be in the bridge. It had been mostly standing for a couple of months before being dismantled, and yet when re-fixed in the bridge, though it had been most carefully measured, by the time the centre of the bridge had been reached in erection the booms were over 6 inches shorter than they had been on shore, and entirely new holes and joints had to be made in them.

Temporary Bridge.—For a bridge of this nature which takes a long time to erect, it will always be worth while putting over a temporary bridge alongside, as one has continually occasion to cross and re-cross oneself and to send over men with tools and materials, and great delay is caused if these have to cross on a wire. Major Aylmer, V.C., R.E., had made a temporary suspension bridge sufficient for light traffic alongside with telegraph wire and light timbers, and this was of inestimable value to us in the erection. It was itself partially wrecked one day by a high wind, which broke the ties and turned the bridge completely over, but the main ropes and anchorages stood firm, and it only took a day and a-half to make good the damages. For lighter bridges that only take a short time to construct, no temporary bridge is necessary, though if one can be easily made, as is often the case at a low level if the water is low, it is nearly always advisable to make one as a means of easy communication from shore to shore for yourself and workmen.

The Indus bridge took a long time to erect, owing to delays caused by want of timber, which had to be procured three miles off, high up the mountains in the snow, and carried over the most breakneck places, and by scarcity of skilled workmen. Only a few skilled labourers were entertained, as they had to be sent up in September to get across the passes before they were blocked by snow, and would not be able to return till June at the earliest. Work had, therefore, to be found for them, and though with good arrangements and ample labour, the actual bridge erection, except masonry and anchorages, could, I think, be easily managed in three weeks, actually two months were spent from the crossing of the first rope to the final completion of the bridge, though traffic was passing over it within five weeks of the crossing of the first rope.

The other bridges were of lighter construction, and a short history and note on each will now be given.

Bridge over Astor River at Ramghat.

Site.—The site selected was at a point where the river runs along the foot of a cliff on the left bank, a very large boulder on the right bank offering a good foundation for the frame.

Anchorages.—It was determined to use a frame only on the right bank, on the left suspending the ropes from the cliff. The right bank anchorages were spare girders from the Indus bridge with similar anchorage rods, and were placed in trenches excavated in the ground, being secured by the rocky boulders in the soil and by heaps of boulders piled on and in front of them.

The left anchorage consisted of similar 2-inch diameter anchorage rods, cut short and fixed about 6 feet into the cliff vertically. Care must be taken to fix the rods well home into the cliff; if there is much leverage the strain of the main ropes will bend the 2-inch rods with ease.

The holes for the rods were jumped with a $2\frac{1}{4}$-inch jumper, and gave trouble; the men were unskilled, and the rock was partially hard and partially soft, so that the holes got crooked and the jumper jambed. It would be preferable, I think, and certainly easier, to put in a number of smaller jumpers. When the holes were ready and had been tested to make certain the rods would go in up to the hilt, the rods were heated, put into the holes, and run in with lead.

This anchorage I had placed too close to the edge of the cliff, and just as the planking of the bridge was being finished we nearly had an accident, as a crack began to show on the cliff, showing that it was giving way. The planking and longitudinals were at once taken off the bridge to lighten it, and as a temporary measure a clip was fastened to the rope where the anchorage seemed especially to be tearing at the cliff, and a tackle was fixed from the clip to a couple of jumpers which had been fixed higher up the cliff for the overhead wire.

For permanency the arrangement sketched (*Fig.* 17, *Plate* IV.) was made. A clip was attached to each of the two ropes of the dangerous anchorage, two rows of six jumpers each were fixed in the rock firmly, the lower row being supported by wire strapping from the upper row, and a $1\frac{1}{2}$-inch circular wire rope was fixed to the end jumper of the lower row, the end being passed through the clips round the next jumper, and so on till it was round all the jumpers. Each return in order was then pulled tight by tackle till a great portion of the strain was taken off the main anchorage, and the end of the $1\frac{1}{2}$-inch rope was made fast by clips. In order to avoid an accident to any one of the pairs of jumpers or the wire round them, endangering the safety of the anchorage, clips were attached to the supporting ropes below each jumper. The bridge erection was then proceeded with, but this caused a delay of over 24 hours.

The fixing of the anchorages took a great deal of time, but all preliminary work was done whilst the timber was being obtained, so that except for this accident no delay occurred to the erection of the bridge.

Strength of Bridge.—The bridge was designed with a 7-foot roadway and a span of 171 feet, that is, 19 bays of 9 feet each. The total load to be carried was estimated at 100lbs. per square foot $= \frac{171 \times 700}{2240} = 54$ tons total weight on the bridge. The strain at points of support, assuming a dip of 1 in 12, is approximately $54 + \frac{54}{2} = 81$ tons. Therefore, four $4\frac{1}{2}$-inch circular steel wire ropes, with a breaking weight each of 72 tons, will give a f.s. of

$\frac{4 \times 72}{81} = \frac{4 \times 8}{9} = 3{\cdot}5$, which is ample. The bridge will, therefore have two ropes on each side.

Scantlings.—The bays were made 9 feet, and the convenient $1\frac{1}{2}$-inch circular rope was used for suspension wires, being amply strong. The points of support of the cross-beams are 8 feet apart. The size of cross-beams can then be obtained.

$$W = \text{breaking weight in cwts.} = 5\text{f.s.} \times \frac{9 \times 8 \times 100}{112} = \frac{8bd^2}{8};$$

$$\therefore bd^2 = 321.$$

Beams may be $8'' \times 5''$.

3 longitudinals weight on centre one $= \frac{9 \times 700}{2} = 3150$lbs.

$$W = \text{f.s. } 5 \times \frac{3150}{112} = 141 = \frac{8bd^2}{9} \quad bd^2 = 158.$$

Therefore, a $4'' \times 7''$ beam will do. The planking is 3 inches.

Girders.—There is no horizontal girder, and the handrail consists merely of strutted posts with a top rail strapped on, and diagonal cross-bracing of telegraph wire. The bridge is, therefore, not very stiff, but apparently sufficiently so for all practical purposes.

Erection.—Jumpers having been fixed fairly high in the cliff, and the anchorages being ready, and all material collected on the flat ground on the right bank, the main ropes were hauled over by tackle attached to the high level jumpers, whilst the frame for the right abutment was being made up. These ropes were got over without difficulty and attached to the cliff anchorage. The frame, as soon as ready, was erected without difficulty by tackle from the high level jumpers and lifting from behind, and was then stayed up by four guys, and the main ropes were then lifted to the top of the frame, made fast to the plain anchorage, and adjusted to proper level, as at the Indus bridge. It should be noted that where one side of a suspension bridge is suspended from a cliff at a higher level than the far abutment, the anchorage for each rope should be in the tangent to the rope at the level of the top of the abutments, both in the vertical plane and also in the horizontal plane, when the ropes are contracted at the centre of the bridge thus (*Fig.* 18, *Plate* IV.).

At Ramghat the cliff anchorages are not sufficiently far apart, with the result that the bridge loses in stiffness. An overhead wire and traveller were fixed similar to those used for the Indus bridge, and the cross-beams were run out. Each cross-beam was ready with suspension wires, upright, and struts attached, and was attached to the tackle by a sling and pegs, allowing of its being readily attached or removed (*Fig.* 19, *Plate* IV.).

Men on a platform on the ropes made the suspension wires fast to the ropes, just as in the Indus bridge.

As each cross-beam was slung out the longitudinals were carried forward, their forward ends being supported in the traveller tackle, and placed in position. The cross-beams and longitudinals were got across very quickly. The longitudinals were then attached by bolts to the side uprights and cross-beams, the planking and ribands put on, and the handrail and bracing attached. The shore ends of the longitudinals were fastened down by lashings to the frame, allowing of horizontal but not of vertical movement.

The timber for the bridge and the men to erect it were at site on the evening of the 8th March, the anchorages had been prepared, and most of the ironwork for the bridge was ready. Traffic was crossing the bridge on the evening of the 18th, and but for the delay caused by the anchorage failure, and another caused by a bad weld discovered in one of the 2-inch anchorage rods after it had been placed in position, the bridge would have been passable on the 16th.

The temporary guys were detached from the frame, and back stays of $1\frac{1}{2}$-inch circular wire ropes were attached from it to the main ropes, about 20 feet back from the frame (*Fig.* 20, *Plate* IV.).

The tendency of the frame is to lean forward under the oscillation of the bridge. The back stays are required to keep it vertical.

Bridge over the Astor River at Garikot.

This bridge is of similar nature to that at Ramghat, but presents a peculiar feature in that it consists of one span of 162 feet, *i.e.*, 18 bays of 9 feet, and a half-span of 81 feet, *i.e.*, 9 bays of 9 feet. The anchorages consist of logs buried in the ground, with strips of $2\frac{1}{2}$-inch iron, 4 feet long, placed at the back, to make the ropes bear more evenly over the logs.

Defect.—The sketch of the bridge (*Plate* II.) shows clearly the construction. It has a serious defect. I calculated the weight of the half-span as only balancing the weight of half the main span, with the consequence that, to equalize the strains over the centre frame, I gave to the half-span a dip of $\frac{1}{6}$ instead of $\frac{1}{12}$, as in the main span. The effect has, of course, been to pull up the centre of the main span, which has now nearly 3 feet of camber, whilst the half-span has none at all. It was practically impossible to alter the arrangement, as I was away at the time the defect was discovered, and did not return until the bridge was practically completed. The dip should, in such a case, be as great for the half-span as for the whole span, and the rope from the end of the half-span to the anchorage should be horizontal (see *Fig.* 21, *Plate* IV.).

In the case of the Garikot bridge, the traffic has to turn sharp under the ropes leading horizontally to the anchorage, so that some modification of the dip would have to be given, and the bridge roadway would have had to be lowered a bit. For ordinary camel traffic or cavalry, headway of 9 feet will suffice, though 9 feet 6 inches is better.

Straining Wires.—It will be noticed on the drawing that there are wires stretched from the top of one support to the top of the other across the main span. These wires are fastened to clips attached to the ropes leading to the anchorages, and the object is as follows :—Supposing the bridge to be accurately balanced on either side of the triangular support. Then a heavy weight coming on to the half-span will tend to drag over the rope from which the main span depends, as shown in sketch (*Fig.* 22, *Plate* IV.), lowering the half-span and raising the main span.

The light overhead rope attached at XX transfers this strain from the short span to the further anchorage, and counteracts the tendency of one to sink and the other to rise. Similarly, a wire is stretched from in front of the triangular pillar at Z to the anchorage of the half-span to counteract the effect of moving weights on the main span.

Erection.—The erection of this bridge was done similarly to the others. A rope was got across in an ingenious way by attaching a very light line through a bullet, coiling it up carefully in a cartridge case, in which a very small charge of powder was placed, and firing it out of a gun. A heavier cord was then fastened to this, and thus the log line and others got across. A temporary bridge was made from the shore to the rock, and the pier on the rock was built up piecemeal by sending out the pieces on the traveller as required. It had, of course, been first put together on shore.

Points to Remember about Suspension Bridges.

1. The less the dip and the closer the ropes to the cross-beams at the centre, *cæteris paribus*, the stiffer will the bridge be.

2. Bring the ropes considerably closer together at the centre than they are at the points of support. So will your bridge be safe from side oscillation.

3. You *cannot be too careful* to obtain a secure anchorage. Making the anchorage takes as long or longer than erecting the rest of the bridge as a general rule.

4. *Practically test* to somewhere a little above working strain all anchorage bars and supports of suspension arrangements.

5. For erection, get some temporary bridge over if possible.

6. Always put up an overhead wire.

7. Have plenty of pulleys and light rope.

8. Make up everything you can on shore, and fit it there. It is difficult to get men to work well and quickly on a shaking platform.

9. If you can manage it, put your bridge high enough up to allow of you having wind ties vertically under the bridge.

10. With ropes contracted at the centre, horizontal wind ties are unnecessary.

11. Never fix wind ties so low that they can be reached by a flood. If strong, *débris* may collect in them and destroy your bridge.

12. Trim your planking as in *Fig.* 23, *Plate* IV.

It is worth the labour, as planks of uneven thickness when laid together and thus trimmed do not trip up horses and men as they are apt to when the corners are square (see *Fig.* 24).

Since writing these notes on suspension bridges, I have read the paper contributed by Major Aylmer, V.C., and would like to mention a special point on which he lays stress, and which I found immaterial. He considers it necessary that the bridge construction should proceed equally from both ends.

I found that exigencies of site compelled me to erect all my bridges from one end only, and no practical inconvenience occurred from so doing. Of course, the bridge whilst only partially loaded assumed a shape differing materially from that it was meant to, but as the construction proceeded the bridge began to straighten, till, when the rope was equally loaded throughout the span, it regained its proper deflection throughout.

It will in most cases, I think, be found convenient to collect all the material at one side, and I do not think that erection would be greatly hastened, using the overhead wire, if an attempt was made to construct from both ends.

When the planking is laid, or, in case of a horizontal girder, when the temporary roadway is down on the cross-beams, work can be done conveniently from both ends, or at any point on the bridge.

Notes on Military Suspension Bridges.

Merits of Suspension Bridges.—With a few trained men, and any possibility of obtaining sites for anchorage, which can almost invariably be obtained, of all forms of bridges for crossing ravines in mountainous countries the suspension offers most advantages.

(1). Insignificant streams sometimes rise to an extraordinary extent after heavy rain, or from melting of snow in glaciers at the head of the ravines feeding them, and an ordinary bridge with piers is liable to be carried away, when a suspension bridge, admitting of one clear span, is perfectly safe.

(2). The procuring of large timber in mountainous countries is often a matter of extreme difficulty, or even of impossibility.

A suspension bridge utilizes to the full the lightest of timber.

(3). For large spans, a suspension bridge is the lightest and easiest to erect of any form.

(4). The weight of individual pieces of a bridge can be kept down to almost any required extent.

The suspension bridge for mountain roads where wheel traffic is not required offers, therefore, distinct advantages. Almost any material—manilla rope, grass country rope, telegraph wire, etc.—can be used for the main ropes and suspension wires, and any small pieces of wood can be utilized for the platform.

It is, however, proposed merely to consider the question of a suspension bridge equipment which would be useful on service.

Weight.—The first point to lay down is that the weight of any individual piece must not be more than can be carried on a mule or pony, and, as these get weak from hardship, it would be safe to put the maximum weight of any one piece as 160lbs. Even very small donkeys can carry this weight if necessary.

Main Ropes.—The $1\frac{1}{2}$ inches diameter *steel wire* (all steel, no hemp cores) rope made by Bullivants, with a breaking weight of about 10 tons, appears exceedingly suitable as an unit for the main ropes. It is very flexible, and can be coiled into a neat and easily managed coil.

Its weight is about $1\frac{1}{4}$lbs. per yard, so that the maximum length admissible is $\frac{160 \times 4}{5} = 128 = 384$, say 400 feet.

It would be preferable to have two coils, each of 200 feet length, the ends being fitted with coned junction pieces, as in sketch (*Fig.* 25, *Plate* IV.), so that two lengths can readily be joined together.

A number of these junction pieces and covers should also be carried, so that if it is necessary to cut a rope, the portions can be readily joined again.

Load on Bridge.—For all ordinary purposes a bridge with 6 feet roadway, and capable of sustaining a weight of 300lbs. per foot run, will suffice.

Cross-beam.—Assuming a distance of 7 feet for each bay, the weight to be carried by each cross-beam is $7 \times 300 = 2{,}100$lbs. = say 1 ton.

Then, with a f.s. = 4 (for military purposes)—

$$W = 4 \times 20\text{cwt.} = \frac{8bd^2}{7}.$$

$$\therefore 70 = bd^2.$$

Therefore a beam $4'' \times 5''$ will suffice, even for very inferior timber.

A beam 10 feet long, $4'' \times 5''$, of green pine, will weigh about

$$10 \times \frac{4' \times 5}{12 \times 12} \times 40 = 55\text{lbs.}$$

Longitudinals.—With three longitudinals, each will carry a load of $6\frac{2}{3}$cwts.

$$\therefore W = 4 \times 6\tfrac{2}{3} = \frac{8bd^2}{7} = 27.$$

Therefore $2'' \times 4''$ will be ample.

The weight of each longitudinal 8 feet long

$$= 8 \times \frac{2 \times 4}{12 \times 12} \times 40 = 18\text{lbs.}$$

The weight of $3 = 18 \times 3 = 54$lbs.

Planking.—The planks should be $8'' \times 2''$, and 6 feet long.

The weight of each will be 26lbs.

The weight of 10 required for each bay will be 260lbs.

Uprights.—The handrail uprights should be $4'' \times 3''$, 3 feet long.

The weight of each will be 10lbs., and of the pair 20lbs.

Struts.—The struts can be of $3'' \times 1''$ plank, 3 feet long.

Weight of each pair = 5lbs., and of the two pairs 10lbs.

Handrails and ribands should be each 3″ × 3″.

Weight of each, 18lbs.; of the four, 72lbs.

Unit.—If the bridge is to be carried as a unit from the base, all these would be made of the best and lightest materials, and the weights might be reduced by $\frac{1}{5}$.

The weight of a bay would then be—

Cross-beam	44lbs.	(Right side of load).
2 Uprights	16lbs.	
4 Struts	8lbs.	
3 Longitudinals ...	44lbs.	(Left side).
2 Pieces Handrail ...	28lbs.	(Left side).
2 Ribands	28lbs.	(One right, one left) = 168lbs. = 1 load.

10 planks = 200lbs. = $1\frac{1}{4}$ loads.

All necessary iron fittings, the suspension wires, and arrangements attached to the cross-beam, should be carried with the cross-beam load, the weight of which will readily admit of it.

The cross-beam can be fitted with handrail upright, struts, and suspension wires, as shown (*Fig.* 26, *Plate* IV.), making a compact load enough.

Standard Bridge.—Taking the standard bridge as 140 feet span, or 20 bays of 7 feet, for which a 200-foot rope will ordinarily suffice, the weight on the bridge will be 20 tons, and the strain on the ropes 30 tons, at the point of support, with a dip of $\frac{1}{12}$.

Allowing the ropes to be worked up to 4 tons, eight ropes will be required—four on each side.

Exclusive of frames, anchorages, tackle, and tools, the carriage required to transport a section of 140 feet = 20 bays is as follows :—

4 pairs of ropes 200 feet long each	= 4 ponies.
20 bays, cross-beams, etc. ...	= 20 ,,
20 bays, planking...	= 25 ,,
	49, say 50.

Ordinarily it would be unnecessary to carry planking, and possibly longitudinals.

Suspension Wires.—The suspension wires could conveniently be of $\frac{3}{4}$-inch circular wire rope—not solid wire. They should be covered at both ends, and fitted with plates and bolts as light as consistent with strength (*Fig.* 27, *Plate* IV.), so as to be readily fixed into one pair of wires. A considerable proportion should be made much longer than required for the unit bridges, and clips (*Fig.* 28, *Plate* IV.) should be carried, to allow of their being fixed on the wires above the main ropes to adjust the length of the suspension wires.

Universal Pattern.—Then, by joining ropes as required, and adding extra bays, the unit bridges can be used for any span required. Thus for a 300-foot span, giving the same dip of $\frac{1}{12}$, the weight to be carried $= \frac{300}{7} =$ number of bays $= 43 = 43$ tons.

Number of ropes required $= \frac{43}{4} = 11$, say 12 or 10, according to circumstances $= 24$ or 20 200′ ropes.

Number of bays required $= 43$.

Probably a much lighter form of steel cross-beams and longitudinals could be adopted.

Anchorages.—Anchorages can be made by driving rows of jumpers into rocks, or by burying logs or sandbags, or heaps of stones, fastened together by an angle-wire net. They must be quite secure.

Frames.—As a rule, the frames would be of wood. They can, however, be built of a rough wood and stone construction where big timber is wanting, the suspension ropes passing over wall plates on the pillars.

It is possible that light adjustable frames would be worth carrying. It would be advisable, certainly, to design them, and have them kept at the base ready to replace the temporary supports as soon as convenient.

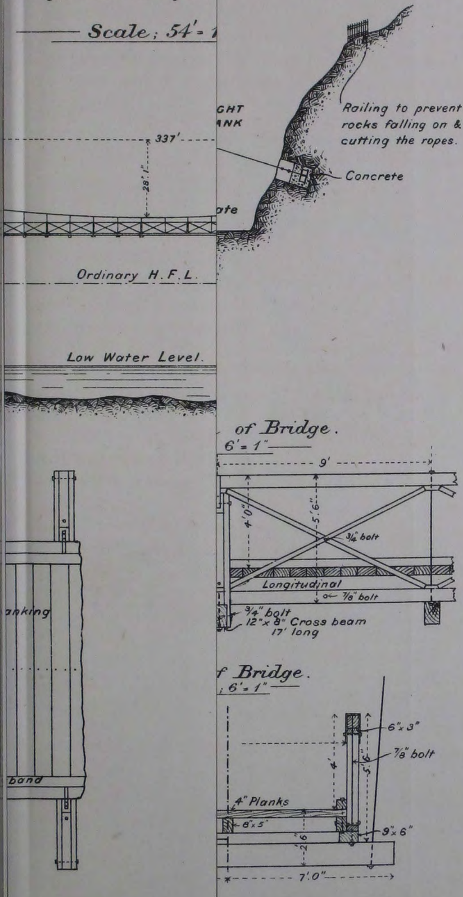
The above are merely rough notes on a bridge equipment, meant as a hint to anyone who may have the leisure and taste to work one out. With the notes of methods used in the erection of the bridges on the Gilgit road, I think a very complete equipment for a suspension bridge train for mountain warfare can be devised.

ON SUSPENS

PLATE I.

Bridge near Bunji.

Scale; 54' = 1



PAPER V.

THE FORCES MADE USE OF IN WAR AND THEIR PROPER APPLICATION.

BY MAJOR C. B. MAYNE, R.E.

(*A Lecture delivered on the* 31*st October*, 1896, *before the Irish Military Society at Dublin*).

I.

I MIGHT have given my lecture the title of "The Philosophy of War," which, perhaps, would more properly have described what I am going to say, for there must be a philosophy of war of some kind or other that controls the operations of war just as every thinking man has a philosophy of life that controls his acts. The truer and more complete the controlling philosophy, the more complete and wide-reaching are the acts and effects that flow from it. But no British writer has yet dealt with the subject of the Philosophy of War, although, perhaps, it would be hard to overrate its importance. However, I am going to ask you to consider with me some of the chief elements of what are, to me, the most vital facts of our military profession.

The subject matter of this lecture has occurred to me again and again when reading various public periodicals and papers, both military and civil, and noticing the very superficial manner in which military and other warlike questions are often dealt with therein. We live in an age of hurry, and I often fancy that many people think that any time devoted to looking below the surface of our immediate necessities is so much time wasted. However, expediency can never be a reliable rule in any affair of human life, and those who are content to be governed by it can only live in a world of seeming confusion. They cannot detect the trend of the main stream or tendency of events amidst the local eddies, side-currents and back-washes that surge on the surface around them. Such people soon become content with the facts or details they see around them, and learn to look on them as real existences, and not as merely passing outward or visible effects of certain fundamental, underlying and invisible principles acting in and through a certain temporary condition of things. In the military world we are apparently simply overwhelmed with details, and with efforts to make existing details or methods of action fit into any new conditions that the whirligig of time compulsorily imposes on us. This naturally results in seeming confusion, but only to those who look on the surface of things. But I am going to ask you to look with me below this surface. I need not enumerate to you, gentlemen, the host of military questions continually pressing for solution, and the varied, and often contradictory, opinions that are freely offered in connection with them. To what agency, then, shall we turn for help, in order to ascertain the old question, "What is truth?" Perhaps one answer will come readily to your lips, and that is "History." That is the answer I should also give. True history is a faithful record of facts that have occurred and of the causes that produced them, but it is rare that we can ever obtain a complete statement of *all* the facts and their motive causes, and some of the omitted ones may be the very ones we want to gain a true insight into what really happened, and into the underlying moving causes. Hence the crucial problem is "How are you going to handle history, with its more or less imperfect record?" Then, again, no two periods of history offer the same external conditions to enable us to truly compare one set of events with another, for not only do the events themselves differ widely in details, but their very environments are widely different, such as the current ideas of the age, the material means available for use, etc., etc.

For these reasons I consider that the only true method of historical study is such a one as will enable the student to ascertain *why* such and such things occurred in the particular way that they did, and what were the underlying moving causes or principles of action and the medium through which they had to operate. The medium is not of permanent importance, as it changes with time; but the underlying principles are unchangeable, being part and parcel of our very nature. And it is these permanent principles that we ought always to try to ascertain by going below the surface of the visible facts and details we see around us, and which are only the outcome of the underlying principles acting in and through the existing medium of current affairs. Consequently our object in the study of all history (and even our daily papers are to be to some extent included under the category of history) should be to ascertain the fundamental principles of action underlying the recorded events. The recorded events or visible details are nothing more than the local and temporary application of fundamental principles amid the then existing condition of things or medium in which they acted. The fundamental principles are permanent in character, and these alone can be our trustworthy guides through all the turmoil and confusion of our daily personal and professional lives. The details, or events that occur in any particular period, are only of interest as illustrating how the invisible fundamental principles broke out into visible local action in the midst of the then existing condition of things or medium at the particular time and place, and with the particular people involved in the transactions recorded.

I may here utter one note of warning—one which I personally feel should be constantly borne in mind at the present day. We are nowadays constantly called on to take part in peace manœuvres and in war games and other indoor map studies, and often very great stress is laid on them. Now this very "stress" may be a wise or a dangerous one. In the practices that I have just enumerated there are wanting very many conditions—indeed, in some cases, conditions of the most vital and essential importance—of real war fare, with the resulting danger that, if too much is expected from peace manœuvres and indoor map studies, a very false, and therefore dangerous idea is produced of what real warfare is. In fact, most officers do realize the unreality of many of the things that occur in peace manœuvres and war games. Hence, if before engaging in such practices it is clearly laid down what lessons can be fairly learnt from them and, further, if these practices are so conducted as to chiefly enable these lessons to be learnt, while endeavouring to avoid the teaching of lessons that cannot be taught from the abnormal conditions that exist with such practices, then peace manœuvres and indoor map studies cannot but be productive of the greatest good. In my own humble opinion I think that we have tried to extract too much from these practices, and so tended to somewhat spoil their real usefulness. But I cannot now enlarge further on this matter. I only utter what I consider to be a needful warning in connection with it.

On account of the short time available for such a lecture as this, I do not intend to take any particular historical incident and deduce from it the fundamental principles of action underlying it. All that I shall attempt to do will be to show you what appear to me to be the fundamental operative forces in war, and their proper mode of application, leaving it to you to trace them out at your leisure in the records of history.

Now the first question that must be asked is *What is War?* Undoubtedly it is a political act. It is the manner in which nations seek to impose *by force* their separate wills on one another when diplomacy has exhausted all its resources, either to gain the desired end peacefully or to find out some basis of mutually advantageous concessions to avoid extreme conclusions. I have no intention to discuss what the national will on any subject should be. But a national decision having been arrived at, either through the discussion of party politicians or the public press, or by other means, as to what is considered to be best for the interests of the nation, then comes the enforcing of this decision, if it be considered of sufficient importance, on the will of such nations as refuse to bend to it. This can only be done by the application of force, and to apply this force, a nation that desires to have an independent existence must have means or instruments for the purpose. Briefly speaking, these means are *The Navy* and *The Army*, which are, consequently, political weapons for enforcing, if necessary, the policy or will of the nation on such other nations as will not allow of this policy being carried into effect in any other way.

As regards the actual act of war, I think that the people of Great Britain have much to learn concerning it.* There is a far too prevalent idea that war only means a duel between two hostile organized and trained units called armies. This idea is an absolutely false one. War is a national act, that is, an act of the whole nation and not of any small part of it. To impose the national will—the *raison d'être* of war—means the annihilation or capture of the means of resistance possessed by the opposing nation, while sufficiently preserving from destruction our own means of compulsion so as to be able to effect this; and the enemy's means of resistance are not merely confined to armed men and armoured armaments, but include all that affects the welfare and prosperity of the nation, that is to say, its manufactures, trade, commerce, banking, stores

* See Appendix, p. 110.

and magazines containing articles and food required for daily or ordinary consumption, arsenals, dockyards, seats of political influence, leaders of public thought and influence, newspapers, railways, shipping, telegraphs, canals, rivers, towns, territory; in fact, everything that belongs to the nation and that plays a *rôle* in its daily life. War is a brutal act of force between nations, in which one nation seeks to cripple another by every means in its power, in order to compel its submission at as an early a date as possible, for war is an expensive operation to indulge in. The long wars of the past centuries were due to forgetfulness of this fact, but the truth of it was brought to the front again by Napoleon I., and it has been the fundamental principle underlying the great wars of this century. Those who wish to read modern history correctly must remember this.

Of the two great instruments for applying national force—the Navy and the Army—I only intend to speak of matters affecting the latter. Not because I desire in any way to minimize the *rôle* of the Navy, but because I am not competent to speak about it. I believe that our special Imperial conditions demand an assured mastery on the seas as essential for our continued existence as an independent Empire. But I cannot believe that, given a navy capable of maintaining that mastery, there is any the less necessity both for a home service army adequate to deal with any possible invasion of our shores, and for a foreign service army adequate to preserve our over-sea possessions from aggression. A navy or sea force cannot do much more than (1) create favourable conditions for the subsequent use of an army or land force and (2) protect sea-borne commerce—both of which duties are of the very highest importance. But the maintenance of a navy and an army involves the expenditure of money. Both are expending departments, and not revenue-making departments of a country, and consequently the spending of money on them is not viewed with favour by party politicians, except when the shoe begins to hurt from external pressure. Germany, Austria and France have all learnt, under the pain and humiliation of great national disasters, the lesson so clearly enunciated by the French Government Committee in 1873, when reporting on the proposed new organization for the French army: "The maintenance of the strength of an army [and we must also add a navy] is an annual premium of insurance against foreign invasion and dismemberment of territory. You cannot diminish the premium without diminishing at the same time the safeguards of the country.

Forgetfulness of this fact has cost us two of our most patriotic provinces and 5 milliards."* As to the relative expenditures on the army and navy, and the strength of each, that is a question to be decided by each nation for itself in accordance not only with the actual total circumstances of the nation, but also with its policy and future aspirations, because the successful accomplishment of both these latter considerations can only be assured by the possession of adequate force to carry them into effect.

II.

Confining my remarks to land operations alone, we associate the word "war" with the operations of armed and trained "organizations" called *Armies*, the movements of which, previous to and on the battlefield, are respectively called *Strategy* and *Tactics*. Now what are the inner and essential principles underlying these words—*Army*, *Strategy* and *Tactics*? For if the concrete application of these things do not fully and truly express their inner principles, so far as the medium in and through which they are compelled to act permits, then, according to the extent of our departure from the ideal, to that amount we fail to realize the best results. I do not pretend that the ideal has ever been reached, but those who approach it nearest are those who are most assured of success, and the old saying that "the best general is he who makes the fewest mistakes" is but another way of expressing what I have just stated. I am afraid that too many people attach a constant value to names denoting things which, in their nature, are essentially variable. For example, the words "army," "infantry," "cavalry" and "artillery" mean the same thing to them, as an element of fighting power, independently of such prefixed adjectives as English, Egyptian, Dervish, etc. But any thinking military man knows that the military value attached to any one and all of the words—army, infantry, cavalry and artillery—is purely relative, depending entirely on the condition of things to which they are applied.

Now the crucial question to be considered is, what are the causes that produce this relativity in value of concrete names?

I will first take the word *Army*. It is in the first place an instrument by which compulsory force can be exerted, but this compulsory force, viewed as a whole, is a combination of a host

* £200,000,000.

of minor forces or elements, and the value of the total force depends both on the separate values of its numerous force-elements and on the manner in which they are combined for employment. Consequently an army is a very complex thing and difficult of proper direction, and this fact will be more plainly seen when we come to deal with the conditions under which it has to be used. But I may say in passing that both *Strategy* and *Tactics* are general terms used to express the systematic and methodical employment, under two different conditions, of the numerous force-elements included in the word "Army," the first being applied to the condition of things that exist before and up to a battle, and the second to the condition of things that exist during a battle.

Again, it is necessary to bear in mind that an army has to be more or less viewed as an organism, or, perhaps, more properly speaking, as an organic body, in which all the various parts are closely inter-related and inter-dependent in such a way that if any one part fails to do its duty, either in reference to itself or to the other parts, then the whole body is weakened to a still greater degree relatively, because the failure of any one part prevents the others playing their proper *rôle* for the success of the whole. It must be ever borne in mind that it is the success of the army *as a whole* that we desire to obtain, and not the success of any one part of it at the risk of the failure of the whole. As a rule, the chief failures in practice arise from the want of a correct sense of proportion or balance between the various component parts of an army and of their respective *rôles* in the great drama of war, and especially of that phase of it that we call "battle."

An army is an organism in so far that—like all organisms—(1) it possesses a vitality of its own and peculiar to itself; (2), it is always undergoing waste; (3), it requires a constant supply of suitable material to replace that waste; (4), it is necessary that this supply must not be uninterrupted for too long, or else the organism will die a natural death; and (5) it must be given an environment and mode of living suitable to its peculiar character, if it is to be maintained in its fullest powers. Further, this organism, an army, is not an isolated body capable of free movement in any direction; at least it is very rarely so nowadays, and then only under very peculiar and favourable conditions. In its normal condition it is only a relatively free body on account of its being connected by a feeding tube (the line of communications) to a base of supply. The longer the feeding tube the greater is the difficulty of getting supplies along it, especially if it is narrow, because this tube itself is an organism requiring and consuming food and other supplies and demanding a special environment suitable to the *rôle* it has to play; and it is just as important that this tube shall not be cut for any lengthy period as it is that the army at the head of it shall not be destroyed by force. At the same time, the army can, by means of its own powers, *if free to act*, draw into itself whatever local supplies it finds in its immediate vicinity. In the days of bows and arrows, and when men fought with weapons designed for breaking open the metallic casings that their opponents hid themselves in, the necessity of lines of communication or feeding tubes connected with a friendly source of supply was not felt. Armies then simply lived on the country and relied on their own inherent powers and the supplies that they could pick up during their rovings. But a modern army, with its complex armaments and the special supplies required for their use, demands a line of communication for its maintenance and sustenance, and the direction that this line of communication or feeding tube has to take is more or less compulsorily indicated by the totality of the conditions imposed by the country through which it has to pass, and the political and military situation.

Thus far I have dealt with the general external appearance of an army as a whole, but, as I have said before, its value as a weapon for compulsion depends largely on the "force value" of its various component parts and on the manner in which these parts work together for the common end—the annihilation of the opposing nation's means of resistance. These means are: (1), the enemy's army with its attached feeding tube or line of communication; and (2) the enemy's territory and sources of supply from which he obtains all he wants in men, horses and supplies of all kinds to maintain his army in existence. And though I cannot, in the time allotted to me, enter fully into the subject, yet I may point out that one of the most important elements of the force of an army is the manner in which the nation to which it belongs acts in unison with it in keeping it supplied and in seconding its efforts in every way in order both to give it the greatest chance of success, and to avoid hampering its movements in any way by raising unnecessary obstacles. This element of success has unfortunately not been a prominent one in many of our wars.

We must now analyse an army and consider the character of the numerous "force-elements" of which it is composed, and which, combined together make the army a national instrument for compulsion. These "force-elements" are not only of different *classes*, but of different *kinds*, while they are *limited* in quality, *expendible* in nature, and possess a variable capacity for activity or energy.

There are two *classes* of force-elements, namely, the visible and the invisible, and each contain various *kinds* of force-elements.

As regards the various *visible kinds of "force-elements,"* we find their equivalents in the armies of all ages, and even in a single man, viz.: (1), distant action by means of thrown projectiles; (2), close action by means of brute strength combined with skill in the use of hand weapons; and (3) speed of movement. In these days we find these visible "force-elements" respectively represented by artillery, infantry and cavalry armed with projectile-throwing weapons; by infantry and cavalry armed with hand weapons; while cavalry and mounted infantry are used for purposes requiring speed. These troops are designated the "Arms" of the service, and the basis of each are impressionable men and horses, possessing only a limited quantity of physical strength and nerves. The ultimate units of any fighting force are but living creatures after all, and limits do exist beyond which endurance cannot go. This fact is the keynote of all that has to be done and can be done in war, which is, at basis, an affair dealing chiefly with human nature. This human nature is endowed with moral, mental and physical energies, of which, other things being equal, the moral are by far the most important to consider. These are the *invisible kinds of "force-elements"* to be found in every army. The moral qualities are those arising from courage, mutual confidence, patriotism, zeal, devotion, hatred, etc. They have the most powerful influence over the mental and physical qualities. In men, considered individually or collectively, these various qualities, whether considered separately or together, vary within very wide limits, and they are each capable of being either largely increased by suitable training and favourable conditions or decreased to almost a vanishing point by unfavourable conditions. Any variation in one acts on the others for good or evil, and these variations can take place even hourly, and as they have no assignable mathematical value, their estimated effectiveness in war can only be a matter of judgment on the part of the leaders. Hence the great value of trying to endow the three-fold qualities of human nature with as high and constant a character as possible, in order to enable the leaders to depend upon them, in moments of great moral, mental or physical strain, with as much certainty as is possible.

This is by far the most important object of drill and military peace training.

The men* and horses of the various arms should be *physically* trained to speedily move over, when equipped, as great distances as possible before exhaustion sets in, while the men should be trained to skilfully use their weapons so as to enable them to employ them efficiently for a considerable time without undue exhaustion. The men have to be fed and kept supplied with all they can possibly want, not only as men, but also as soldiers, and provided with shelter at night. The horses and other animals (pack and slaughter) have to be fed and kept in good condition, for they lose their strength when underfed and overworked, and when kept for long under trying and exposed conditions. So that the physical energies of an army vary with the exhaustion of its men and horses, with the quality and quantity of the food and other supplies they receive, with the degree of comfortable rest and shelter they get. All these, again, depend on the state of the roads, the climate, the state of the soil and its cultivation, the weather (rain or sunshine, etc.), the condition of the men's boots, etc.

The men of the various arms should be trained *mentally* (1) in their professional duties so that they may understand intelligently what they are doing, and may carry out orders in their spirit and not in their bare letter only, and (2) in the intelligent technical use of their weapons so that they may obtain the best effect from them. Hence the mental energies of an army vary with the quality and quantity of the professional and technical training that the men have received individually and collectively.

Again, the men of the various arms should be so trained as to increase their *moral qualities*, especially in the direction of *discipline, which, in its essence, is self-sacrifice*,† and which may be also called "acquired courage." *The first instinct of human nature is that of self preservation*, however well equipped a man may be physically and mentally. *This instinct, for war purposes, must be overcome by the higher will-power of self-sacrifice.* If men will not face death and danger and prolonged hardships by an act of the will, they are no good for the object and purpose of war, which necessarily involves the possibility and probability of death, danger and prolonged hardships. Discipline

* Including officers in this term.

† This definition of discipline was first brought to my notice by Capt. E. Nash, late R.A. I have not seen it so defined by anyone else.

is often defined as "obedience to orders;" but this is only a part of discipline, a part of the principle of sacrificing self to the good of the whole in obedience to the expressed orders of those in authority. Those who only look upon discipline as obedience to orders fail to realize its full *rôle* in war, and why it is that discipline is the quality that, generally speaking, converts a mob of armed men into an army. But this discipline must be intelligently carried out, and hence the necessity for a concurrent intellectual training for the men, especially in these days of fighting in extended order, which has distinctly loosened the personal control of the superior leaders over their units when these latter have once been sent forward under fire. Like the physical and intellectual qualities, the moral qualities also vary greatly with the character of the men composing the army, and the nature of the moral training they receive. The better the class of men obtained as recruits, the better and higher is the discipline that can be ingrained into them. This is one advantage of universal conscription, *i.e.*, of a conscription that taps all classes of society. But in any case it is to be remembered that discipline is an acquired virtue, and that it can only be acquired slowly, which is an important consideration affecting our auxiliary forces, for the shorter the period of training the less is the amount of that all-important quality of discipline that can be instilled into the men. We want to ingrain into our soldiers such a discipline as will make them stand firmly under a long-continued strain of danger, hardships and discomforts, perhaps seemingly inglorious, but all the same often necessary for the ultimate success of the whole army, and not merely a discipline that, under the excitement of the pomp and glory of so-called warlike surroundings, will temporarily cause self to be forgotten for so long only as the excitement continues.

We have further to remember that the physical, intellectual and moral forces of human nature are closely inter-related, and that any variation in one of these affects the others. Thus, when undue physical exhaustion occurs, the intellectual and moral powers are seriously lowered and often rendered incapable of action. Again, if the intellectual powers are low, men will not fully realize the urgent necessity for self-sacrifice, and also will not know how to act properly under the varying conditions that rapidly follow one another in war, while they are liable to get disheartened at any seeming confusion or temporary want of success, or when their leader is put out of action. But most serious of all is any failure of the moral energies. Just so long as the will-power for self-sacrifice is strong, men will struggle on to do their duty in spite of danger and of physical and intellectual exhaustion ; but without this will-power they will collapse under the least strain. And thus it is that we must lay the greatest stress on the development of the moral qualities of each of the individual men composing an army, although due corresponding and concurrent attention must also be paid to the development of their intellectual and physical qualities. The qualities of an army are only the aggregate of the qualities of the individuals composing it, including those of the superior leaders and of the commander of the whole, and hence the vast importance of the personal training of each and every individual belonging to an army, in accordance with their respective positions, duties and corresponding responsibilities. If opportunities for this training are not given by the nation, then the real blame of any failure lies on the nation, and only on the individuals of the army in so far as they did not make use of such limited opportunities as they could have made use of had they willed to do so.

The chief means we have for instilling discipline into soldiers is "drill," and the "smarter" this drill is the more effective it is for the purpose. The smartest and best drilled troops are those who have the best and most discipline, and are consequently those who can be most relied on in moments of great moral, mental and physical strain. Manœuvres are but the application of drill to a particular end, and the better and smarter the drill the better the manœuvring power of the troops. Thus drill is only a means to secure discipline and manœuvring power, and consequently well-drilled troops are far better than ill-drilled troops for war purposes History is full of facts corroborating this, though there is a strong tendency to overlook it in this country. But discipline and manœuvring power must be supplemented by instilling into the men a high sense of their duties and great skill in the use of their weapons, and this can only be effected by "education." Hence drill *and* education must go hand-in-hand together to turn men into soldiers, and the more we have of drill and education, in both proper proportions and quality, the better the men will be as soldiers.

I have pointed out that there are two classes of force-elements, viz., the visible and invisible, and that there are three kinds of visible force-elements and three kinds of invisible force-elements that we have to deal with. But each of these six kinds of force-elements have various subdivisions, and though a consideration of each of these is of importance, time will not permit me to do more than bring the fact to your notice. And I must further note the fact that not only are the two classes of force-elements closely inter-related, but also the various kinds and their subdivisions. In fact, we must always remember that we are dealing with an organism and not with a piece of machinery.

The force-elements that I have so far spoken of, and which receive their visible embodiment in what we call an army, are by no means constant quantities. Indeed, they are extremely variable, and are liable to daily change within wide limits, when severely tested by the strain of deteriorating conditions involving death and danger, and by prolonged hardships due to long marches, bad roads, bad or hot weather, unhealthy climate, insufficient food or water both in quantity and quality, etc. Consequently, as our object should be to maintain the force-elements at as constant and high a value as possible, every effort should be made to minimize the effects of such deteriorating conditions when they have to be compulsorily faced for executing the operations of the army, viewed as a whole. Those who needlessly impose such conditions on any of the men or horses of an army incur a very grave responsibility on account of either culpable ignorance or culpable carelessness.

The force-elements of an army in the field are also, at any given moment or place, both limited in quantity and expendible in character. These are very essential facts to bear in mind, and point to the absolute necessity of a line of communication, or feeding tube, capable of repairing the waste or expenditure. The larger the army the wider is the strip of territory, as a rule*, over which it can advance, the easier is the working of its supply or feeding tube, and the more readily can any expenditure of force-elements be replaced, although it must never be forgotten that all replacements of any such expenditure take *time*, which is often a most momentous consideration in war. In order to terminate a war as quickly as possible, the largest force possible, suitable to the conditions of the war, should be employed. A long-drawn-out war, weakly prosecuted, is always a costly proceeding; but the size of an army is regulated both by the probable quantity and quality of force-elements that the enemy possesses, by his probable use of them, and by the facility with which both the country operated in and the line of communication can

* As an exception to this rule, I may quote the Afghan War, where the lines of advance were confined to certain widely separated and narrow valleys.

maintain the army in all its food, ammunition, and other requirements, and replace the constantly occurring expenditure of its force-elements. These same considerations must also be applied to the enemy's army. In the Peninsular War a small army found it hard to overcome the opposition it met with, while a large army would have starved. In this as in all other considerations of human affairs, a balance of opposing and conflicting interests has to be struck, and the decision rests on judgment alone.

We have further to bear in mind that in war, *i.e.*, the national application of compulsory force, it is very desirable for economic reasons that the settlement of the disturbing question that has caused the war should be effected at as an early a date as possible. To do this we require to ensure a continuous application of force so long as force has to be applied. An intermittent application of force is an evil, because it permits the enemy to recuperate himself for fresh efforts of resistance. It must further be remembered that a war is rarely terminated by a single application of force, but by a series of successive applications, which should follow one another with the greatest rapidity possible, as such a course not only shortens the series, but rapidly reduces the enemy's means of resistance to such a point as to compel his submission. Hence the extreme value of vigorous and prolonged pursuits after a victory, or of preventing such a pursuit after a defeat. After a serious defeat an army is necessarily disorganized or broken up as an organism, and its force-elements are demoralized and incapable of energetic action. Consequently the fruits of a victory can only be gathered after the actual defeat, and this can only be done by a vigorous and prolonged pursuit, which in many instances has alone brought about a termination of hostilities.

The reason why war is composed of a series of efforts or applications of force is because a nation's means of resistance are two-fold—(1), its army; and (2), its means of maintaining and supplying this army. The whole army of a nation is rarely engaged at one point, and its means of supply lie scattered over the whole country. Consequently both have to be subjugated by degrees, though the enemy's army is the primary consideration, for as soon as that is reduced to submission the enemy's means of supplying it are useless to him, and he has to submit. Consequently for such reasons it is imperative that the national means of compelling submission, that are put into the field, should be as powerful as the conditions of the country operated in will permit. This is a case when seeming extravagance is true economy, for nothing is so costly as either failure in warlike operations or a prolonged prosecution of them owing to want of strength to compel the enemy into a speedy submission.

III.

Having thus very briefly pointed out what constitutes the force-elements that are visibly embodied in an army, I must now also briefly refer to the necessity for their *regulation*, in order that they may be systematically and methodically applied. It is only by such a systematic and methodical application of the force-elements that we can ensure not only their most effective use separately, but also their opportune use collectively. The first thing to do is to organize the fighting men into regular units with recognized leaders according to the visible force-elements that they are going to employ, and to arrange for the daily supply of all their needs by means of suitable administrative services and supply departments, which, in order to serve the fighting units, must conform to their wants and necessities, and not *vice versâ*, as occurred on the French side in the Franco-German War, to the great detriment of the French operations. The staff and supply departments of an army are to serve, and not to be served. It is for them to maintain the fighting units or organized force-elements in a fit condition for fighting, and also to secure for them the most favourable conditions for success.

As a fighting organism, an army wants to be able to make use of distant action by thrown projectiles, of close action by brute force, and of speed. Consequently, to secure these objects, some of its units are armed with guns, others with rifles and bayonets, others with machine guns, others with sword and lance, while some move on foot and others are mounted. According to the various groupings of armament and mounting, we get the various organized units designated by the terms infantry, artillery, cavalry, machine gun detachments, mounted infantry, and engineers. But no one of these terms absolutely expresses a given fixed quantity of force-elements independently of its antecedents. Even in the same army one "infantry battalion" is not always equal to another as a visible embodiment of certain force-elements. So also with regard to cavalry regiments, artillery batteries, engineer companies, or any other smaller or larger organized unit, or grouping of units. And the variations of the force-value of any of the above terms are still wider when they refer to different nationalities. These vitally important facts have to be considered by every leader in the field, for in the application of force against force the nature and character of the force-elements of both sides have always to be considered--at least by a wise leader.

The relative proportions of infantry, artillery, cavalry, machine guns, mounted infantry and engineers required to form an army cannot be definitely stated, as they must vary both with the character of the force to be overcome and the nature of the country in which the operations are to take place. They can only be decided on by judgment, based on past recorded experience, due consideration being given to any material changes in the conditions of things that have taken place in the interval (*e.g.*, progress in the means of transportation of men and supplies, or in means of rapidly conveying information, or in the destructive power of armaments, or in the value of the men and leaders as trained soldiers, etc.).

But having decided on the size of the army to be used and on the proportions of the various arms in it, these various arms are grouped, separately or in combination, into regular recognized units under appointed leaders, and each having their own staff and supply services, in order that they may be systematically and methodically employed, according to the will of the superior leader of the army. And in carrying this out we must bear in mind that an army is not a collection of independent arms. It is an organism in which the various arms are materially dependent on each other for success, and for the triumph of the whole army. This is a vital principle. Cavalry and artillery are not, in the highest sense, auxiliary arms to the infantry. They are part and parcel of a single fighting organism, in which one arm (or grouping of force-elements) or another is more prominent for a while at different stages of the struggle. The only true auxiliary arm is the engineer arm, which is essentially a handmaiden arm; and, being a handmaiden arm, it should thoroughly study and understand the requirements of those whom it has to serve. Artillery, using distant fire only, is the leveller of obstacles, moral, intellectual, and physical. Cavalry, using mobility and brute force, acts both as the "senses" of an army before battle and also as a "hammer" in battle. The infantry arm partakes somewhat of the nature of these arms, but it has not the same power of distant fire action as artillery, nor the same power of mobility in close shock action as cavalry. Hence each of these arms supplements the weakness of infantry; but neither cavalry (which has no fire power to speak of) nor artillery (which has no shock power) can fulfil their true *rôles* alone. They only find their fullest power when acting in conjunction with one another and with infantry, each arm supplementing the weak points of the others; for it is the mutual self-sacrificing action of the different arms that is essential for obtaining the best results, and consequently is one of the secrets for securing victory.

The same remark applies to all the elements—fighting, staff, and supply—of an army. So far as they do not work together as interdependent parts of an organism, so far is an element of weakness and even of danger introduced, and the evil spreads, not in arithmetical, but in rapid geometrical proportion. Consequently not only are the elemental units and grouping of an army of importance, but also its internal organic machinery and the inter-relation of its various parts and the manner in which they mutually serve and assist one another at all times and under all conditions. The whole difficulty consists in striking the right balance between these individual and collective actions and duties.

I have already pointed out that war consists, as a rule, of a series of efforts. And this fact forms another imperative reason for the systematic and methodical grouping of both the force-elements and the supply-elements of an army, in order to ensure not only their orderly and continuous operations, but also as great a rapidity as possible in the series of continuous efforts that it should ever be our object to effect for the purpose of crushing the enemy's means of resistance at as an early a date as possible.

IV.

I have hitherto considered all the force-elements of an army as a united whole capable of simultaneous action. But such a supposition rarely happens except in the case of very small armies The necessity for rapid movements, for feeding, watering and housing the men and animals on the line of march, for ensuring good sanitary conditions, and for appropriating to one's own use the resources of the enemy (or at all events preventing his own employment of them), requires the dispersion of the army over a sufficiently wide area for that purpose. But when a battle is to be fought it is necessary to concentrate every available grouping of force-elements for that purpose, even to the temporary abandonment of minor operations and objectives, in order to secure success where the danger is greatest. And here I must call your attention to the fact, too often forgotten, that *in all critical affairs of human life there is always a centre of gravity*, using the word "gravity" in the sense of danger or importance—and it is for those engaged in these critical affairs to find it out, and to deal alone with it, if they desire success. Concentration of effort at the vital spot, rapidly and energetically applied, is in every department of life the rule of success. But neither the position nor the character of this centre of gravity are constant. In war the centre of gravity may one day be the enemy's main army, the next day some important and influential town or person, while soon after it may be the threatening attitude of some hitherto neutral nation, etc. But at all moments of a war a centre of gravity exists, and it is against this centre that the operations of the army must be directed, so as to deliver on it a brutal, smashing and stunning blow. War is a brutal act, and blows must be brutally dealt in rapid and unrelenting succession, if the enemy is to be reduced rapidly into submission. The centre of gravity is the vital spot for the time being, and as it is the enemy's vitality we wish to render powerless, we must strike home there with all the energy possible as soon as the centre is recognized.

But as the army during movement is disseminated over a wide area, we see that the intensity of its power for action is not always the same, but this does not matter so long as the objective to be struck at is still at a distance. But as this objective is approached, the scattered groupings of force-elements must be drawn together in opportune time, and at the right place. Any mistake made as to time or place is an element of weakness, and even of danger; even too early a concentration is to be avoided, from the difficulty that such a concentration causes of rapidly moving and easily feeding the troops, and also because it favours the production and spread of contagious diseases. The enemy's power of holding together for long after concentration must also be considered, especially in irregular warfare.

But this act of concentration requires *time*, and hence, in order to possess the power of timely concentration, an army must have both the means of securing timely information about the enemy and the groupings and movements of his force-elements, and also the means of conveying such information, however unimportant it may seem, to the commander of the army. I do not intend to enumerate the various means available for this purpose, beyond saying that much can be effected in peace-time, while during war the work falls largely on the mounted arms belonging to the army, which should be pushed out for the purpose sufficiently far to the front and flanks to give timely warning for concentration. It is essential that the *whole* of the front and flanks be so covered and watched. In fact, the advanced mounted troops act like a barometer. With a high barometer or distant advanced troops, fair weather or no danger is indicated, but with a low and rapidly falling barometer, that is, with the advanced troops near at hand, bad weather or danger is indicated. The nearer the advanced troops to the main body the more concentrated the groupings of the force-elements of the latter should be.

However, it is most essential for success that the means of securing, transmitting, and sorting and comparing information, and of issuing orders based on them in proper time for them to be acted on, should be carefully thought out and practised in peace-time. The art of judging what a more or less invisible enemy is doing by visible indications, often only slight ones, has not been adequately studied or written on yet. But the difficulty in all this work lies in the fact that the enemy is doing his best to veil, both by force and by spreading false information, his own strength, dispositions, movements, and intentions; and consequently all the operations of a war are carried out under conditions of more or less ignorance as to the enemy's strength and doings—which may be called the "fog of war." Indeed, it often happens that the commander of an army is even in ignorance of what many of his own units are doing, either from information not having been sent, or, if sent, not having reached him through some accident or unforeseen contingency.

In all this question of collecting information and issuing orders based on them in opportune time, we must carefully bear in mind that we are dealing with human beings endowed with feelings of ambition, jealousy, hopes, fears, desires, affections, etc. It is a common fault for men concerned in a common danger to consider that the centre of gravity is exactly just where they happen to be, and to direct their actions accordingly. Many leaders, too, get carried away with a desire to distinguish themselves by what they consider to be some brilliant deed conceived by themselves. Others are fearful, and see danger when there is none. Others are jealous, thinking that they have not been given a sufficiently important *rôle* to play, or that they are purposely neglected and kept out of the way of winning distinction. Others are excellent men for peace work only, and so earn a reputation which breaks down under the strain and rude test of war. Others are careless, and think that there is no danger, when they are really on the point of being annihilated. I do not suppose that any campaign ever took place in which some such disturbing causes did not play a considerable part. Then, again, accidents of all kinds frequently occur. Messengers are thrown and injured, or are captured, or go astray for want of a proper knowledge of the country; bridges relied on for crossing streams by are found to be broken; torrential rains suddenly occur, reducing the power of marching on which the leader's calculations have been based; unexpected opposition from a party of the enemy is met with; and so on. Further, orders that have been sent are often misread and misunderstood, either from want of clearness on the part of the sender or from want of appreciation on the part of the recipient. Or orders may be issued based on a false conjecture as to what is taking place. All this has to be considered, besides the possible daily variations that occur in the moral, mental, and material force-elements of the individuals employed on the work.

The moral to be drawn from all this uncertainty is that minutiæ in calculations must be strictly avoided, and very large margins of safety allowed for. Even in engineering works, dealing with material bodies of more or less constant quality, we engineers have to allow for factors of safety five to ten times the calculated theoretical strains; how much more should we not introduce such factors when dealing with such an uncertain material as human nature, embodied in multitudinous individuals all endowed with such variable qualities that no two are alike? It is to reduce this uncertainty to the greatest possible extent that we soldiers lay such great stress on the introduction of discipline, or the spirit of self-sacrifice, and of education and training into the force-elements of an army, so as to secure the united action of all its force-elements to a common end at the same time and place.

V.

I have now to briefly refer to the conditions that limit our power of applying force. I will do so first in relation to *strategy*, which is the methodical and systematic manipulation of the organized force-elements of an army, in such a way as to try to be strongest at the right time, and on the right battle-field. This means not only trying to conserve and concentrate opportunely your own organized force-elements, but also trying to induce the enemy to keep his organized force-elements dispersed.

Our power of applying the force of an army is limited by (1) the time required for moving and concentrating the dispersed organized force-elements; (2), the obstacles to effecting rapid movements; (3), the position of the centre of gravity or point of applying force; and (4), the feasible directions in which the force can be applied at the selected point.

I have mentioned that the power of action of an army as a whole varies inversely as the space over which it is distributed; and we must remember that the enemy will try and deceive us in order to keep our force so distributed while he strikes at it. Hence the time required for concentration, and the information known about the enemy's army, limit the application of force. This question of information, or rather want of information, is a very serious one, and has often hopelessly clogged leaders gifted with only average moral and mental energies. They forget that the enemy is probably surrounded by the same difficulty or fog, and that the only way of clearing the fog for yourself and making it thicker for the enemy is to advance boldly and rapidly and take the lead or initiative, and so to make the enemy act in accordance with what you do. It is very important to bear in mind that every question of war must be considered from both sides as far as possible, and in doing this it is also neces sary to remember that the same or similar difficulties are being encountered by the enemy as we ourselves are experiencing. The first one who determines to take the offensive or initiative, and burst through the besetting difficulties, gains an enormous advantage over his opponent, as he thereby decreases his own difficulties and increases those of the enemy.

This forward movement, or the *offensive*, as it is generally called, is one of the most essential elements of success. There is a mechanical law which defines the energy of a moving body as its mass multiplied by the square of its velocity. The spirit of this law holds good in dealing with the organized force-elements of an army; the force represented by an army, when concentrated opportunely, is immensely increased by the rapidity with which it is used. In fact, the brutal, smashing, stunning blows that we desire to deliver are impossible without mobility, for without rapid movements on our part the enemy can concentrate in time to oppose such a force to ours as will prevent the blows of the required nature being given. The power of rapid movement depends largely on the physical strength of the men and horses (which is capable of being increased by proper training and feeding and housing), on the weight of the guns and wagons of all kinds behind the teams drawing them, and on the method of their groupings. But suppose the enemy has outwitted us, or is stronger than we are at the hour of trial, then we are reduced to a *defensive* attitude as a whole, which, however, does not preclude offensive action in parts, but *in any case a defensive attitude must only be looked on as a temporary preparatory attitude for a subsequent offensive movement, to be made when opportunity offers a reasonable chance of success.* But I will not now say more on this matter than to state that neither side, if properly led, will willingly adopt a defensive attitude. It is forced on that side which, at the moment of decision, is relatively the weaker when the balance of political, strategical, administrative and tactical considerations has been struck.

Then, again, the very nature of the country operated in, and the existence of efficient hostile fortified places in the area of the operations, limit the application of force. All these things can be included under the head of "obstacles" to the movement of the army as a whole. Deserts, mountain ranges, broad, rapid and deep rivers, efficient fortresses, bad roads, wide areas that have no food and water resources, either from natural or artificial causes, etc., all limit the direction and rapidity of the application of force. We have even to consider the friendliness or hostility of the inhabitants of the country. If they are really hostile (patriotically so), then the movements of the army can only be slowly and difficultly made, for want of formation and of supplies, and from the difficulty of maintaining intact the feeding tube, or line of communication.

The point of application of force is limited by the position of the centre of gravity of the situation of affairs at the time. It is necessary to strike a smashing blow at the vital spot for the time being. When this has been done a new state of affairs is created with a new centre of gravity, and there the next blow has to be struck as soon as possible. It is rarely that no centre of gravity can be detected; if such a thing occurs, then all we can do is to acquire territory up to the safe limits of occupation, and then wait for a centre of gravity to become visible, as it will do in time.

The application of force is limited also by its having to be applied in certain directions only at the selected point of application, and, further, we must remember that when force is applied in some directions it meets with less resistance and produces greater results than when it is applied in other directions. The line of communication must not be uncovered unless there is a good certainty of success, while every effort must be made to cut the enemy's line of communications. Again, applications of force on the flanks of an enemy are of greater value than on his front, as his flanks are his weak points, and if defeated then, he is driven off his line of communication, or feeding tube, instead of back along it. But if the enemy is widely distributed it is a good plan to pierce his front in order to separate his forces, and then to rush at each separated part, and smash it up before they can be joined together again. But in doing this a judicious distribution of the force-elements of the army is required. An example may illustrate my meaning. Take two equal forces. The enemy has widely distributed his, and we have pierced his front, and divided it into two portions, A and B. Our general has then to decide at once which of these two portions becomes the immediate centre of gravity, and to march against it with all speed. We will suppose that he selects B. But to secure himself from interference, he has to detach against A a force C, of sufficient strength to hold A in check for such a length of time as will enable the remainder D of the army to defeat B hopelessly. Now C is weaker than A, and D is stronger than B, and yet C fulfils its duty if it secures the desired time, even though it is defeated in battle. D can then, with what is left of C, turn against A after leaving a detachment to complete by pursuit the discomfiture of B. Here we see an example of judgment in weighing circumstances, and securing the balance of advantages to ourselves. This is the ordinary rule of action of successful men in conducting the affairs of life, and its application in war is, therefore, no novelty, though many second-rate leaders have failed to recognize it.

Although we must recognize the fact that the application of compulsory force is usually limited in its energy of application and direction of application, yet it is the bounden duty of every leader to try and secure for himself the greatest possible freedom of movement or means of applying force while endeavouring to reduce that of the enemy. Every step in war must be one of gaining advantages for self and raising disadvantages for the enemy, while remembering that, if we are in difficulties, the enemy has his difficulties also. A weak leader is usually overborne by his own apparent difficulties, and, seeing no further than his own limitations, quails before imaginary danger of his own creation. Also, we must always remember that the freedom of application of force that we desire is enormously facilitated by a dynamic and not a statical use of it. Indeed, a statical use of force is the best means of robbing it of all true freedom of application, and this is why the offensive is always to be preferred to the defensive whenever the former can be used without absolute danger. In war, boldness (though not rashness) is the best policy; but in our usual wars in uncivilized countries the magnitude of the force employed, its energy of application, the point of its application and the direction of its application are all more or less strictly limited by the physical conditions of the countries operated in.

The subjects of *outposts* and *advanced guards* really belong to the province of strategy, though they are usually considered in detail under the head of Tactics. This may be done for the sake of convenience, but the strategic *rôle* of outposts and advanced guards should ever be borne in mind. They are used (1) for guarding the main body or grouping of force-elements from immediate danger until it is ready for action, and (2) for collecting what information they can of the enemy while preventing him from gathering any. Both of these duties primarily relate to strategical problems.

I cannot leave this subject of strategy without referring once again to the importance of a dynamic use of the organized force-elements composing an army, or, in other words, to the importance of mobility in executing the marches by which the organized force-elements are massed and utilized. This mobility depends on many factors, such as the physical strength of the men and horses, which in turn depends largely on their peace training; the loads they have to carry or draw; their feeding and housing, both in quality and quantity; the proportion of hours devoted to rest compared to those spent in labour; the length of the columns of march; the quality of the discipline or spirit of self-sacrifice ingrained into the various human force-elements; besides the delays caused by the enemy's advanced detachments and by the natural and artificial obstacles met with. But in every case the greatest energy of movement possible under the actual circumstances of the case must be sought for.

And we must further remember that, in war, for every day's fighting there are many days of long and trying marching. Before ever a foe is seen, rapidity of movement in getting over long distances will often be urgently required, and in such a way as to still possess a sufficient reserve of energy for fighting purposes at the end of the march. To secure this power the greatest care must be taken to reduce as much as possible the weight carried by the men and behind teams, and to practise the men and horses of all arms during peace-time in executing long marches at a good rate. This is a most essential point to bear in mind, especially if we remember that the roads that have to be made use of in war, as well as the weather, are often very bad and trying to both men and horses.*

It is very necessary to bear all this in mind, because the tendency of a prolonged peace is to make men dwell rather on the technical powers of their weapons than on the manœuvres which bring about their judicious application. The effect of fire can be measured on a target, while that of a charge or of a rapid march requires actual hostilities to give illustration of its value. But target practice we have every day, while war experience comes but rarely, and thus we are apt to forget the vast importance of mobility.

VI.

I have now to briefly refer to the conditions that limit the power of applying force in the sphere of *tactics*, which is the methodical and systematic employment of the organized force-elements of the concentrated army so as to be strongest at the right time and place on the battle-field itself. And in the sphere of tactics we have the same four considerations limiting the application of force on the battle-field as we have in the sphere of strategy on the whole theatre of the war. Strategy is the art of using battles to compel an enemy into submission; tactics is the art of defeating the enemy in battle. Thus both strategy and tactics react on one another. A bad strategy will place an army in disadvantageous conditions in front of a superior enemy, and then only superior tactics can save it, but without being able to deliver the smashing blow which it is the object of good strategy to secure. The true object of war, the rapidly effected annihilation of the enemy's means of resistance, can only be properly secured by both good strategy and good tactics. A bad strategy can be saved by good tactics, but the best strategy is of no avail with bad tactics.

In the sphere of tactics we are again confronted with the fog created by a want of exact information concerning the enemy. The various organized force-elements on each side have been previously

* This subject is well brought out by Major E. S. May, R.A., in his work on *Guns and Cavalry*.

concentrated and drawn up facing one another, but neither side knows the strength nor distribution of the organized force-elements of the other side; and hence both sides have to act on conjecture. Here, again, the offensive is the best attitude to adopt if the balance of all the factors in the problem seem to be in your favour, remembering that the enemy is enveloped in much the same fog as you are, and that it is an enormous advantage to lay down the law to him and to make him follow your lead. And for the offensive to be possible we must have mobility as a prominent characteristic of our organized force-elements. But here we are confronted with the difficulty that, when opposed to civilized and well-armed troops, who have been well trained both technically and tactically in the use of their arms, an immediate application of brute force is impossible unless we can apply it well on his flank or rear or by surprise—conditions which are rarely present in anything like favourable form. The result is that the application of brute force has to be preceded by a wearing-down process, in which each side tries (1) to disorganize the organized groupings of the opponent's force-elements, and so to create confusion in his ranks and make his men incapable of being controlled or led, and (2) to demoralize and even destroy the very force-elements themselves of the opponent, while (3) endeavouring, as far as possible, to prevent its own organized force-elements from being unduly disorganized and demoralized. Each side is trying to do this with more or less success, with the consequence that both sides suffer considerably before the deciding application of brute force is made. And here we see again the immense importance of an army having as one of its greatest force-elements the spirit of discipline or self-sacrifice. The very fact that each side tries to "demoralize" and "disorganize" the other side shows the vital importance attached to the moral forces (of which discipline is the chief) and to preventing confusion taking place. Men in confusion soon lose their moral energies and become fearful, and then rapidly comes the panic state, in which men act on the impulse of self-preservation alone, heedless of all commands. This impulse of self-preservation, which doubtless will come in time in any case, if the men are tried long enough and severely enough, can only be staved off by the power of discipline, and we may say that the probability of victory lies with that side which has the greatest amount of moral energy left, as the leading factor in its force-elements, at the moment of applying the decisive brute force.

The want of exact information about the enemy's strength and dispositions, and the fact of this preliminary wearing-down process, (which often lasts for some hours) of necessity leads to all actions being based on conjecture, and to many of these conjectures being erroneous. But, then, as both sides are in the same predicament, the false conjectures are but rarely punished as mere theory would dictate, and as is often demanded in war games and peace manœuvres. But the one great lesson to be learnt from this is that no leader should engage in battle without ample reserves to rectify mistakes, to execute opportune counter-attacks, and to replenish or revive the worn-down force-elements that have first been thrown into battle. Such reserves are required both locally and generally, and all good dispositions of units for battle must provide for both local and general reserves in ample quantities, due consideration being paid to the opposing force-elements and the probable method of their application. Another great lesson that must also be remembered is the avoidance of all finnicking details in the application of our force-elements. Such details can only be useful or profitable when exact knowledge is available. But exact knowledge is never available in war. We are then dealing with conjectures which are very liable to be wrong, and the effects of these can only be righted by a bold and fearless application of decidedly superior force. Those who look on battle as a game of "long bowls" will never effect anything. Such men are usually those who are unduly influenced by the technical progress of arms and their performances under peace conditions. The technical perfection and use of weapons is one thing, their tactical use (introducing the human nature factor) is another. In battle, decisions can only be made at short ranges, and whatever preparatory action is necessary, our object must always be to arrive in strength at the short or decisive ranges, to mass our force-elements there, and then to use them offensively, vigorously, fearlessly and brutally. Hence, never waver as to whether to use overwhelming force whenever possible, and always remember that the energy of such a force is greatly increased by its dynamic use, that is, by its offensive employment. Brutal, smashing and stunning blows are required in tactics as well as in strategy, and such blows are all the more effective the more rapidly and brutally they are delivered. And the army that is on the defensive must try and do this as well as the attacking army. All mistakes made by the latter, and any demoralization and disorganization that he is suffering from, when he has approached so near that his own artillery has to cease firing, must be taken advantage of in opportune time by directing against him vigorous counter-attacks made by more or less fresh troops. Indeed, the soul of the defence lies in such opportune counter-attacks, and this is all the more important to remember because in peace manœuvres the demoralization of the attackers cannot be simulated, with the result that counter-attacks then have an air of unreality, and consequently attempts to execute them are discouraged, and so they soon cease to be attempted. Hence to carry them out in battle demands a great act of faith.

But the delivery of decisive blows is limited, among other things, by the respective capabilities of the various groupings of the organized force-elements of the army, viz., the cavalry, artillery, infantry (foot and mounted), machine guns, engineers, etc., *i.e.*, of the various arms of the service. Mounted troops (whether mounted on horses, cycles, or carts) can move rapidly, seize and hold points of vantage (such as defiles of all descriptions*), and gain information over a wide area (a most important consideration), while some mounted troops, such as cavalry, can utilize their speed in battle by rapidly applying brute force by charging in a solid mass, though this cannot be safely done against well-armed and well-trained troops until they have first been disorganized or demoralized, or unless they are surprised and charged before they are prepared to meet the onset. The artillery and machine guns can only act by means of the projectiles they throw and consequently their proper use at first is at a distance, though their material and moral effectiveness rapidly increases as the range decreases. The artillery force-elements must especially be used with brutal energy and vigour, and for this they require great mobility to enable them to be freely and quickly massed where and when required, and their efforts concentrated on such selected points as are most vital at the time, and at the shortest ranges possible. Without great mobility the concentration of guns will be that of an unwieldy mass, and their technical hitting power may prove to be of little avail from their not being able to move up to effective ranges. Infantry can act in a double capacity, with rifle and bayonet, at a distance and by brute force. This double capacity, combined with the greater relative ease and the cheapness of raising, equipping and training infantry, has made this arm the predominant one in modern armies. So much is this the case that many writers almost imply that the other arms are

* Bridges, woods, passes, villages, etc.

only auxiliaries to the infantry arm. But this view I have already protested against in my remarks on an army being an organism. The engineers are only a small fraction of an army, and are handmaidens, their duty being chiefly to provide for the technical wants of the other arms at moments when these other arms are otherwise engaged in other vitally important duties. Thus the respective capabilities of the various arms must govern the application of the force-elements that they embody, due consideration being given to the corresponding strength and groupings of the force-elements of the enemy and his probable way of applying them.

The numerous textbooks now published are largely devoted to explaining the application of the organized groupings of the force-elements of an army, and consequently I do not intend to go closely into this subject, but I must refer to certain broad principles affecting them. Before a battle, we have the two hostile armies approaching one another with their various groupings of force-elements in columns of march, preceded well ahead by their respective mounted troops, both of whom are seeking for information while trying to prevent the enemy from acquiring it. When the mounted troops of each side meet, and are checked, the distance that separates them from the marching columns in rear diminishes, the war barometer falls, and the columns are brought nearer together, until they actually stand side by side on the day of battle, that is to say, if the information collected has been good, if it has been well interpreted, and if it has been properly acted on—a goodly number of "ifs" which are rarely met with in proper combination. Much might be said about the organization of the marching columns, and the distribution in them of the various arms—the principal question for settlement nowadays being, shall there be a grouping of corps artillery or not?

These columns have next to deploy for battle. One army is usually able to effect its deployment before the other, namely, the army that is going to temporarily adopt the defensive attitude. The mounted troops gradually clear away from the front as the long-distance-acting force-elements come into action, and when a sufficient force of the infantry arm arrives for their adequate protection. How shall these distant-action force-elements (artillery and machine guns) be distributed, and how used? We want to inflict a brutal, smashing, stunning blow. This must be the constant object to be kept in view. But where shall be the point of its application? and when shall the blow be delivered? If the blow is to be made on a flank, then there must be means of moving round to this flank unseen and unsuspected, the arrangements for which usually lie in the province of strategy. But before the blow can be delivered the enemy's opposing organized groupings of force-elements must be disorganized and demoralized, and this is best effected by rapidly inflicting on him severe losses at as short ranges as is possible. To put 1,000 men out of action in three hours at long ranges has not, in any way, the same effect as putting the same or even a smaller number of men out of action in half an hour at short ranges. Consequently local concentrations of suitable force-elements must be employed at the shortest possible ranges without trying to enquire as to the exact minimum amount of force-elements that can be expected to effect what is required. The possibility of advance beyond a certain limit is a consequence of fire superiority obtained, and this in turn is determined by the powers of the weapons used and the qualities of the opposing troops to bear losses before giving way. Minute estimates are valueless in the face of want of exact information and enforced conjectural action. Far rather use too much than just enough. Too little means want of success, even if it does not mean defeat. And, again, we must have method and system in the application of our organized force-elements, and of their groupings—advantageous conditions which each side tries to deprive the other of by trying to disorganize its organized groupings. If we think for a moment of all the sub-leaders who play an important *rôle* in battle, and how they are each personally variously influenced by ambition, chance of distinction, impatience, self-will, temper, want of viewing things in their proper proportion, caution, fear, jealousies, dislikes, contempt for the enemy, etc., we can easily see the vast importance of demanding the highest moral discipline attainable among all ranks, together with intellectual professional training, and method and system in all our applications of force. In these considerations many problems crop up for solution, viz., the proper way of utilizing the fire power of our artillery force-elements, whether by dispersion of fire or concentration of fire, locally or generally, or by a combination of both; the division of the application of organized infantry groupings of force-elements into attack and assault; what groupings shall take part in each; how they shall be formed, in recognized attack formations or not; what fronts are to be taken up by the attack and by the assault; how is the time and place of assault to be hidden from the enemy; when, and where, and how are the cavalry force-elements to be used in battle; etc., etc. But in every case we must remember that the artillery arm is the greatest means we possess for levelling obstacles to our progress, whether they be moral or material, and that the best way of using it as a leveller is to mass it and to concentrate its fire with brutal energy at the shortest possible ranges. This must especially be done just before the assault. So great is the levelling power of the artillery force-elements that Frederick the Great said: "The fewer guns brought into action the more human blood has to be spilt."* The practical acceptance of this truth is shown by foreign armies having lately raised the proportion of their artillery arm from 3 guns per infantry battalion (of 1,000 rifles) to 5 guns. We have not gone so far in this matter, for an English army corps has only 108 guns against the 120 guns that a foreign army corps has. "If troops are prematurely sent to the attack, and fail, as they did again and again in 1870 (and in 1877), one of two conditions or both must have been ignored, and this must be due either to the fact that the conditions forced the hand of the leader, or that the leader did not understand his work, and committed the troops to a task beyond their strength. 'Storming a position,' said Moltke, 'is like fording a river; whether it is possible or not depends upon its depth. If it goes over your head you are drowned, if the fire is more than your troops can face you are lost.' The analogy is perfect, only he forgot to point out that in the artillery you possess the power of reducing the depth of the river, *i.e.*, the intensity of (the enemy's) fire, to any degree you please, always assuming that you can afford the time."†

One other point I should like to allude to. It seems to me that in all the present attack procedures a very secondary consideration is paid to the application of the force-elements that an armed rifleman embodies. The idea seems to be how to get the man, the symbol, forward, instead of how to employ the force-elements he represents. Both guns and rifles are meant for hitting, and they lose their *raison d'être* if they do not hit reasonably often. The gunners have realized this fact, but in our infantry attacks I am afraid that the importance of handling the extended men so as to secure the fullest possible effect of their fire-power has not been fully considered, with the inevitable result of a very great waste of an invaluable force-element. However, I cannot now enlarge on this. In fact, on all

* See *Achievements of Field Artillery*, by Major E. S. May, R.A.

† See page 12 of 2nd Essay in *Attack or Defence*, by Capt. F. N late R.E.

these and similar questions I should like to say much in the light of the principles I have enunciated, but time prevents my doing so. But I hope that some of my thoughts may prove of use to you in thinking out these questions for yourself. But certain essential requirements must never be forgotten. We must adopt such a method of fighting, that is, such a use of our organized force-elements, as is suited to the strength of the materials with which we have to deal. The old long-service troops could stand greater losses before giving way than the modern short-service troops, because they had more years of drill, and so had a greater amount of discipline. It was not the breechloader that caused the dissolving effects noted in the wars of 1870 and 1877 so much as the reduced discipline of the short-service troops employed in these wars and the faulty manner in which they were sent forward in closed masses under effective artillery and rifle fire. Hence the use in battle of the organized force-elements must be suited to their quality or the strain that they can safely bear. The leader of the army must be constantly kept fully informed as to what is going on at every point of the battle-field; it is probably best for him to arrange for this by keeping near him a number of mounted men to act as messengers. Local and general reserves must be amply arranged for, especially for completing the battle after a successful assault and for pursuit, or for warding off pursuit after an unsuccessful assault. A mere successful assault is not everything. It only provides conditions for further successful operations, which must, therefore, be energetically and brutally carried on, until the enemy gives way in retreat, or lays down his arms. There must be no relaxation of effort until this end is gained. Local leaders must expect temporary ill-success, without in any way relaxing their efforts, in view of the fact that the main effort for victory is being made elsewhere, and when that is won they will recover their lost ground.

Further, as the infantry force-elements form the bulk of an army, it is very essential that the cavalry and artillery groupings of force-elements should be given a certain amount of freedom of action for preparing the way and facilitating the progress of the infantry arm. Consequently, the leaders of the cavalry and artillery arms, and I may also add of the engineer arm, should be fully admitted into the confidence and plans of the leader of the whole force, in order to enable them to properly and fully carry out the *rôles* for which these arms are organized and maintained. This is a very important point indeed to bear in mind.

Although not in strict keeping with the subject, I think that the following table may be given to aid the memory as to the methodical lines of action that underlie the three principal conditions of a soldier's life in the field, viz.: when at rest, on the move, and in battle, or rather in the employment of the force-elements of an army on outposts, on advanced guards, and in battle.

	Outposts.	Advanced Guards.			Battle.	
1	Sentries.	Advanced point			Shooting line	
2	Piquets.	Advanced party	Van guard.		Supports	forming the 1st line.
3	Supports.	Supports		Advanced guard.	Battalion reserves	
4	Reserves.	Main guard			Local reserves	forming the 2nd & 3rd lines.
5	Main body.	Main body.			General reserves	

We here see that for a large force we have a five-fold division in each case (though the relative strengths of each division vary greatly), and that the first four divisions are either for the protection of the 5th or for securing favourable conditions for its decisive action. In using this table I would suggest that it should hold in its entirety for all units of a division and upwards. For smaller units I would always retain the 1st and 5th divisions and drop out the others in the following order:—4th, 3rd, 2nd—as the unit decreased in size. Thus, for a battalion of infantry acting alone in any of the above three conditions, I should drop out 4 and 3. For a brigade of infantry acting alone I should drop out 4. I do not mean to suggest that the above table should be binding in any way, but I only offer it as a useful guide for average action.

I think that it would form a very useful subject for discussion as to whether the present grouping of force-elements in our various units is the best that we could devise. For example, taking the infantry arm, we have eight units in a battalion, four in a brigade, two in a division, and three in an army corps. Personally, I have not been able to unravel the reason for the two-fold formation of the division.

VII.

I must now bring to your notice a force-element that must have already occurred to you, and which has a commanding influence in war, especially if we bear in mind the almost conjectural character of the operations of war. I refer to the influence of the leaders of the various groupings of the organized force-elements and of the leader of the army. It is easily seen that the higher the leader the greater is his difficulty and the responsibility of correctly interpreting the often discordant collection of information he receives, of correctly estimating the centre of gravity of the situation at each moment, and of striking vigorously at it. Hence we see the value of an intellectual training, in professional matters at all events, but, as war is an affair between nations, the higher leaders should also have some knowledge of statesmanship and of the commercial and financial resources of various nations, so as to know the weak points at which they can best be struck. But the most essential characteristics for leaders are not the intellectual ones. These can, if necessary, be supplied by selected staff officers. What a leader really requires are a correct knowledge and judgment of human nature and will-power to put his decisions based on this judgment into fierce action in spite of apparent difficulties. Professional knowledge is not always to be found combined with the moral factors I have just mentioned, although the general supposition is that this combination is the usual one. All leaders are not Fredericks, or Napoleons, or Wellingtons. And hence great allowance should be made for all leaders in war, which fact, however, public opinion, which is very ignorant in such matters, completely ignores. It is most important that all leaders should be trained to form correct judgments on the information that they possess at any moment, which information, however, may be very faulty, and then to exercise will-power in vigorously putting them into action.

History shows us many examples of the baneful effects on military operations of such factors as the ill-health of the commander of the army, want of energy through weakness of his character or on account of old age, and also of impatience, self-will, temper, contempt for his adversary, etc., on the part of a leader. All these and similar factors play an important *rôle* in war, though every effort should be made to guard against them by selecting capable and trustworthy men as leaders.

It is, further, important to ascertain the character of the enemy's leaders. This is done in peace-time as a rule, for many of the most notable operations of war have been very largely based on the estimate made on what the opposing leader is likely to do.* This

* *E.g.*, Austro-Prussian War of 1866.

fact is plainly to be seen in the wars carried out by Frederick the Great, Napoleon I. and Wellington.

VIII.

I must now bring my remarks to a conclusion, and in doing so I venture to state that the national peace arrangements for an army and the training of it should be based on a previous consideration of the force-elements that are used in war, their organized groupings, the method of their application and what is expected from them. I think that at present the nation has by no means realized what war means, and, consequently, has not adequately provided opportunities for its army to properly train itself for war. There is yet a great want of power to see the things of war and for war in their right proportion, some things being favoured all out of proportion to their true usefulness and value because they are visible, tangible and pleasing to the eye. We are too apt to forget that a man is really a sacrament, *i.e.*, he is the outward and visible sign of inward and invisible force-elements. A man may be physically a Hercules, and yet be an inferior creature to a physical weakling who is superior to him in intellectual and moral faculties. We do not want an army composed of merely physically perfect animals, although physical powers are wanted as far as possible. We want an army gifted with intellectual and moral powers as well, and those to the highest degree possible. These qualities or force-elements can only be obtained by a proper system of training, in which peace manœuvres, on an adequate scale and under conditions approximating as closely as possible to those of war, find a large place. But before we can get this it is necessary that public opinion, and also that our statesmen, should know what war is and what is required to enable an army to prepare for it. And I cannot help thinking that the best way of doing this is to constantly put before them the subject of war described in some such terms as I have endeavoured, imperfectly and but too briefly, to explain in this lecture. It is important to first persuade the average mind of the fact that an armed man is not necessarily a "soldier," and then to enforce the truth that a "soldier" is an armed man who is the visible embodiment of certain force-elements, of which discipline is the most important, and that it is these force-elements that should be our chief consideration in order to secure their training and development to the highest pitch possible. Even if we soldiers learn to fully realize this vital truth we shall find our daily routine work rise to a high level and assume a vitally important aspect. Many details, apparently useless and superfluous, will then become full o meaning as means to an end. we shall then find an ideal before us that we can only endeavour to reach up to, but never fully attain. Personally, I cannot help thinking that if such views as I have endeavoured to enunciate of what war and an army mean were constantly kept before every officer and man, our own views as to what our profession means and entails on us would rise to such a high level as to cause us to be far more fully absorbed in them than at present, and thus to prevent so many being crushed and made despondent by the weight of what appears on the surface to be dull routine and red tape. Let us look below the surface of things. The world is a stage and men are but actors in the drama of life, but every actor represents something, and it is that something we want not only to get at and develop, but also to make use of. This is, or rather should be, the keynote of our professional work.

Lastly, I may point out that what I have said shows us the vast variety of the information that we must seek to acquire during peace about all other nations with whom there is any possibility whatever of going to war, if we desire to assure success for our army. How this information is to be acquired I cannot now enter into, but it is essential that it be obtained, and collected before war breaks out.

APPENDIX.

Extract from a speech delivered by Lord Dufferin at Belfast on October 28th, 1896.

"And now I come to the second conviction which has been borne in upon me during my long contact with the outside world, and it is this—that, in spite of Christianity, civilization, in spite of humanitarian philosophics, the triumphs of scientific knowledge, in spite of the lessons of history and bitter experiences of the more recent past, force, and not right, is still the dominant factor in human affairs, and that no nation's independence or possessions are safe for a moment unless she can guard them with her own right hand. Quiet, stay-at-home people in England, who, as their fathers before them for so many generations, have passed their untroubled lives in blissful ignorance of what invasion means, can scarcely bring themselves to believe in the actuality of the ruthless ravages of war, in disaster and defeat raging through the land, with its accompaniments of disbanded armies, violated women, and burning and plundered towns. And yet these scenes have been enacted not so long ago within a few hundred miles of our own borders, and have extended over the greater part of Europe, for not only France, but Denmark, Italy, Turkey, Poland, Bulgaria, Austria, have each in turn been desecrated by the red ruin of many a bloody battlefield; nor have America, India, China, or Japan escaped these awful visitations. And the worst of it is that most of these wars have not been wars of right and wrong, clearly defined and understood, but wars of policy, of passion, of misty interests and obscure origins, and so completely has this been the rule that, in almost every instance, the exact *casus belli* is still a matter of ambiguity and historical dispute and incapable consignment by the puzzled analysts to any precise formula.

"Under these circumstances it would be madness on our part to be misled and deluded by that kind of amiable and benevolent optimism which always prevails among people who have no personal experience of the real, hard, cruel conditions of international existence, or not to maintain in full vigour, both by sea and by land, the preparations necessary for our own preservation. We have more to risk, for we possess more than any other nation on the face of the earth, even in spite of other Powers having recently given, like ourselves, hostages to fortune in the shape of their new colonial establishments. Moreover, though God forbid that the invasion of our shores should ever acquire the character of an imminent danger, we should remember that the safeguard of the 'silver streak' is an ever-diminishing advantage. In former days, the winds were as faithful allies of Britain as her seas; but their virtue has been exorcised by steam, and probably there is not a War Office in Central Europe which does not possess the matured plans of some clever strategist for a descent upon our coasts, either in the shape of a serious attack or a formidable diversion. That both attempts would ultimately fail I have no doubt; but that our weakness should ever engage an enemy to entertain the idea would be in itself a most serious misfortune. Above all things, it should be remembered that the possession of a sufficient strength to command the respect of a nation's neighbours does a great deal more than guarantee a successful defence in the case of unprovoked attack; it also discourages and prevents a hundred irritating, provoking, and impossible demands—nay, it even diminishes the risks of dangerous international newspaper polemics, calming and moderating to a wonderful degree the menacing attitude of a pugnacious Press, for even irresponsible and anonymous able editors think twice before insulting an enemy, however hated, that has half-a-million armed men at its disposal, though they may use considerable freedom towards a far more inoffensive friend who they know might have difficulty in putting, on a critical emergency, half a *corps d'armée* into the field."

PAPER VI.

ON BRIDGING OPERATIONS WITH THE CHITRAL RELIEF FORCE.

BY THE COLONEL ON THE STAFF, ROYAL ENGINEERS.

1. The main engineering feature of this expedition has been the very extended nature of the bridging operations.

2. Immediately on leaving Nowshera, the Kabul river has to be crossed, over which communication is maintained by means of a bridge of boats with a roadway sufficiently wide for one line of traffic only. Upon the mobilization of the force very heavy convoys would be constantly running, and serious blocks of traffic might be expected with this single bridge; it was therefore decided to provide a second one. The boats and superstructure of the Defence Division, Military Works, were accordingly brought up from Attock, and another bridge established. This work was commenced by Major M. C. Barton, R.E., and completed by the Punjab Public Works Department.

3. The two main rivers, the Swat and Panjkora, with which we have had to deal, were both very serious obstacles, especially the former. This river is very wide and rapid in any place where trestle bridging—the only class of bridge for which materials were available at the moment—was possible. The force was fortunate in reaching the Swat at a time when the state of the river made

the construction of this bridge feasible. Even before its completion a small rise rendered the placing of the crates and trestles a matter of some difficulty.

4. From its length alone, about 450 yards, to say nothing of the amount of materials used, all of which had to be carried to the site from a considerable distance, the construction was a work of some magnitude. Once up, the bridge stood wonderfully well, and lasted until a suspension bridge of a permanent character had been completed. It was then dismantled, as it was no longer required. Major M. C. Barton, R.E., was in charge of the construction of this bridge.

5. To supplement this trestle bridge, the pontoon equipment of the Bengal Sappers and Miners was ordered up from Roorkee. It happened to be in position over the Ganges at Hurdwar at the time, but was dismantled, brought into Roorkee, and despatched with commendable rapidity under the supervision of Major J. C. Tyler, R.E., in command of the depôt. Captain G. M. Heath, R.E., who came up in charge, experienced much difficulty in getting it over the Malakand Pass, as the road which had been made up to that time was barely wider than the track of the pontoon wagon wheels, and had many sharp corners.

The maintenance of the pontoon bridge in position, as will be seen from Captain Heath's report, severely taxed the capabilities of the detachment.

6. As neither of the above-mentioned bridges were of a character to stand the floods which might be expected in July and August, the G.O.C. ordered the construction of a permanent suspension bridge as soon as possible. This was started at once, under the direction of Lieut.-Colonel W. T. Shone, D.S.O., C.R.E. of the Line of Communications, and it will be seen from the report of Captain G. Williams, R.E., who was entrusted with its erection, that this, too, proved an unusually heavy undertaking for a work in the field. Nearly the whole of the ironwork for the piers, etc., was made either in the Military Works or North-Western Railway shops at Rawal Pindi by Major E. Blunt, R.E., and Mr. A. Buckland respectively.

7. The two suspension bridges made by the 1st and 4th Companies, Bengal Sappers and Miners, over the Panjkora river were both excellent of their kind. The first one was put up by Major F. J. Aylmer, V.C., R.E., and was remarkable for the rapidity with which it was completed. The second, made by Captain J. R. B. Serjeant, R.E., took longer, but was twice the span and a more finished structure.

8. The suspension bridge over the Chitral river made by Major Aylmer, V.C., has a span of 300 feet, which is the largest attempted during the expedition.

9. The following is a list of the various bridges constructed :—

* (i.). Suspension bridge for pack transport and foot passengers over the Kalapani at Jalala, constructed by Captain H. C. Nanton, R.E., with civil labour.

* (ii.). Bridge over the Sakot Nulla, on the Mardan-Dargai road, designed and constructed by Captain H. C. Nanton, R.E., with civil labour.

(iii.). Trestle and crate bridge over the Swat river, constructed by Major M. C. Barton, R.E , with No. 1 Company, B.S. and M., under Captain J. R. B. Serjeant, R.E., and No. 6 Company, B.S. and M., under Captain F. E. G. Skey, R.E.

* (iv.). Pontoon bridge over the Swat river, carried out by Captain G. M. Heath, R.E., and the Pontoon Section of A Company, B.S. and M.

* (v.). Swat river suspension bridge, built by Captain G. Williams, R.E., with No. 6 Company, Queen's Own Madras Sappers and Miners, under Lieutenant C. Ainslie, R.E., assisted by some 200 civil artificers and by detachments of the Bengal Sappers Pontoon Section when available.

(vi.). Raft bridge over the Panjkora, by Major F. J. Aylmer, V.C., R.E., with the 4th Company, Bengal S. and M.

(vii.). Suspension bridge over the Panjkora, erected by Major F. J. Aylmer, V.C., R.E., and No. 4 Company, Bengal S. and M.

(viii.). Suspension bridge over the Panjkora, constructed by Captain J. R. B. Serjeant, R.E., and No. 1 Company, Bengal S. and M.

(ix.). Trestle and crate bridge over the Jandul river, built by Lieutenant G. C. Kemp, R.E., and the 6th Company, Bengal S. and M.

* (x.). Bridge over the Ushiri river at Darora, strengthened and improved by Captain J. R. B. Serjeant, R.E., with No. 1 Company, Bengal S. and M.

* (xi.). Suspension bridge over the Panjkora at Chutyatan, built by Captain J. R. B. Serjeant, R.E., with No. 1 Company, Bengal S. and M.

(xii.). Suspension bridge over the Chitral river opposite site for the new fort near Chitral, erected by Major F. J. Aylmer, V.C., R.E., with No. 4 Company, Bengal S. and M.

Descriptions of each of these bridges accompany this report, with photographs†, and in the case of Nos. (iii.), (vi.) to (xii.) lithographed drawings† are also attached.

10. Photographs† are also sent of the following minor bridges :—

* (*a*). Alladand Nulla bridge, Captains G. Williams and G. M. Heath, R.E. (*Plate* XXVII.).

* (*b*). Uch river bridge, Captains G. Williams and G. M. Heath, R.E. (*Plate* XXVIII.).

* (*c*). Khongia bridge, Lieutenant H. F. Thuillier, R.E. (*Plate* XXIX.).

* (*d*). Niag river cantilever bridge, 57 feet span, Lieutenant F. R. F. Boileau, R.E., with working party of the 37th Punjab Pioneers (*Plate* XXX.).

* (*e*). Cantilever bridge at Dir, Colonel E. W. Smythe, with 25th P.I. (*Plate* XXXI.).

(*f*). Cantilever bridge at Dir, Khan of Dir and No. 4 Company, Bengal S. and M.

(*g*). Cantilever bridges above Panakot, Captain J. R. B. Serjeant, R.E. (*Plates* XXXII. and XXXIII.).

(*h*). Cantilever bridge above Kolandi, Headquarter Wing, 23rd Punjab Pioneers (*Plate* XXXIV.).

(*i*). Old bridge at Chitral, natives of Chitral (*Plate* XXXV.).

† Many of the photographs and drawings are reproduced with this paper.—Editor, *R.E.P.P.*

11. In addition to the above, 45 smaller bridges were constructed south of Dir, and 24 between Dir and Chitral.

12. The bridges marked with an asterisk were constructed under the orders of Lieut.-Colonel W. T. Shone, D.S.O., C.R.E., Line of Communications. The photographs are by Sergeant F. Mayo, R.E., A Company, Bengal Sappers and Miners.

13. The extended use of telegraph wire was a noteworthy point in the design of the suspension bridges. The experience gained in its use on former occasions by Major Aylmer, V.C., proved of great value, and there is no doubt that it will be largely used on future expeditions when any bridging of this kind has to be done, owing to the ease with which it can be carried by any class of transport.

H. P. LEACH,
Colonel on the Staff, Royal Engineers,
Chitral Relief Force.

DATED AT MALAKAND,
21*st September*, 1895.

REPORT ON SUSPENSION BRIDGE OVER THE KALAPANI RIVER AT JALALA.

The new metalled Mardan-Dargai road crosses the Kalapani river, north of Jalala, at mile 12. The river here flows between sandstone cliffs, about 250 feet apart and 50 feet high.

The metalled road crosses the nullah by long graded approaches, but there is no bridge, because, when the road was constructed, the rains were approaching and foundation works would have been liable to damage by floods.

The Kalapani is usually a petty stream, not more than one foot deep, and is easily crossed, but rain in the adjoining hills or surrounding country causes a considerable rise of water, and three and a-half feet depth renders the nullah impassable on account of the rapidity of flow. Recently, three times during one week, the river rose so as to stop all traffic, each time for half a day; and the river has been known to rise 25 feet and to remain impassable for two days. It was undesirable that the risk of communication being completely stopped should be incurred, and it was evident that sudden rain, with a consequent rise of water, might delay troops returning from the front in the wet on the banks of the Kalapani for some hours.

The Field Engineer, Dargai, represented these facts and reported that there was sufficient timber on stock at Jalala, and steel cable and telegraph wire at Dargai, to construct a light suspension bridge, which could be erected in a comparatively short time.

The proposal was approved, and the Commanding Royal Engineer, Line of Communications, directed the bridge to be built.

Some delay was caused by the telegraph wire on stock at Dargai being suddenly required for the construction of the Chitral Bridge; work was, however, commenced on the 22nd August, and the bridge was open for traffic on the evening of the 7th September.

A site north of Jalala Camp was chosen, and considerable excavation was necessary to obtain level platforms on which to erect the towers.

The clear span of the bridge is 200 feet, the width of roadway being 6 feet. The towers are 24 feet high and the dip of the cables 20 feet, while the roadway is 45 feet above the river bed.

The towers are constructed of deodar timbers, 8 inches square, and take the form of four-legged trestles, which had to be built in two tiers, since no wood longer than 13 feet was obtainable.

The anchors are trunks of large trees buried 8 feet deep in the sandstone. Each suspension cable consists of two flexible steel wire ropes $3\frac{1}{4}$ inches circumference.

The roadway has three $6'' \times 4''$ road bearers covered by $1\frac{1}{2}$-inch planking, and resting on $6'' \times 4''$ transoms, 6 feet apart from centre to centre. The transoms are hung from the cables by tension rods made of telegraph wire, 300 lbs. to the mile, with three wires in each tension rod. The rods are fastened to the cables by stopper hitches formed of the tension rod wires.

Four side stays are provided at each end of the bridge to check the swaying.

The bridge is constructed to carry infantry in single file, or four horses at one time.

H. C. NANTON, Capt., R.E.,
Field Engineer.

Jalala,
7th September, 1895.

REPORT ON BRIDGE NEAR SAKOT, ON THE MARDAN-DARGAI ROAD (*Plate* I.).

Between the 22nd and 23rd miles from Mardan the cart road crosses a tributary of the Kala Pani River. This tributary, which is in ordinary occasions dry, runs in floods, say from 3 to 10 feet, after every heavy fall of rain in the Swat Hills. To prevent seriously stopping the traffic and continual repairs to any temporary road which might be constructed across the bed of the stream, the Commanding Royal Engineer, Lines of Communication, decided to erect a bridge.

A wooden trussed bridge consisting of two spans of 50 feet clear each, resting on each bank on masonry abutments and in the centre on a stout braced double trestle, itself standing on a masonry foundation, was designed by Captain Nanton, R.E., and approved.

A wooden trussed bridge was chosen, as wood could be quickly obtained, and, if not required in long pieces, could be carted over the then kutcha road from Mardan. Much delay would have been caused had an iron bridge been decided on, both in carting the heavy pieces and in erecting at site.

Each wooden truss of the bridge consists of an upper compression boom, a lower tension boom, braces, counter-braces and vertical tie-rods.

The truss is 9 feet high, and is divided into nine panels.

The upper boom consists of three longitudinal strips measuring $7'' \times 6''$ each, and the lower boom of three longitudinal strips measuring each $10'' \times 6''$.

These strips in each boom are placed horizontally beside each other, and kept $1\frac{1}{2}$ inches apart by means of filling pieces.

The braces are in pairs butting against the outer strips of the upper and lower booms. The counter-braces are single, and pass between the braces.

The braces and counter-braces butt against hard wood blocks, triangular in section, which rest against the top of the lower and the bottom of the upper booms. The joints at the heads and feet of the braces and counter-braces are butt-joints.

The vertical tie-rods are in pairs, and pass through the $1\frac{1}{2}$-inch intervals left between the strips of the booms. The pairs of tie-rods pass through the hard wood blocks at the heads and feet of the braces and counter-braces. The head and nut of each tie-rod catches on heavy washers at the top and bottom of the upper and lower boom respectively.

By tightening up the tie-rods the upper and lower booms are brought to bear on the heads and feet of the braces and counter-braces, and the whole truss is set up.

The braces and counter-braces measure $5'' \times 6''$, and the tie-rods are $1\frac{1}{2}$ inches in diameter.

Two trusses per span are used, and the roadway is carried on the lower boom.

The roadway consists of buckle-plates, obtained from Rawal Pindi Defences, resting on $7'' \times 10''$ road-bearers, which themselves rest on the lower booms of the trusses.

The roadway is 12 feet wide. The bridge will carry any traffic, including crowded men The roadbearers are not designed to carry elephants.

The foundations of the masonry are on clay 10 feet below the bed of the stream.

Any piece of wood in the bridge can be renewed from time to time when required. The time occupied in construction, from the laying of the first basket of concrete in the foundations to the opening of the bridge for traffic, was two months.

The work was delayed slightly by the Utman Khel tribe killing some of the workmen at the bridge site.

A photograph of the bridge is attached.

H. C. NANTON, Capt., R.E.,
Field Engineer.

Dargai.
24th July, 1895.

TRESTLE AND CRATE BRIDGE OVER THE SWAT RIVER
(*Plates* II., III., IV., V.).

Constructed by Major Barton, R.E.

On the arrival of the advanced troops of the Chitral Relief Force to the Swat river, it was found that although the river was then fordable, it would soon cease to be so, and thus the immediate construction of a bridge was necessary.

2. *Description of River.*—There was a ford opposite the village of Chakdara, where the river flowed in five separate channels, with low islands between them, and although the distance from bank to bank was some two-thirds of a mile, it was evident that this would be the most suitable site for the proposed trestle and crate bridge, owing to the river being too deep and the stream too rapid in other places, with narrower channels.

3. The width and depth of the various channels on 7th April were as follows (counting from the left or south bank of the river) :—

No. of Channel.	Width.	Approximate Depth.
1	....	Dry.
2	216 feet.	2 feet to 2 feet 6 inches.
3	276 feet.	2 feet to 3 feet 3 inches.
4	....	Dry.
5	372 feet.	1 foot to 2 feet 6 inches.
6	180 feet	2 feet to 3 feet.
7	6 feet	2 feet to 3 feet.

Nos. 1 and 4 were dry when the bridge was commenced, but shortly afterwards filled. Nos. 2, 5, 6, 7 could be forded fairly easily, while No. 3 was even then difficult and almost dangerous.

4. *Depth.*—The depth of the river changed considerably from time to time. The rise due to snow water was small and very gradual, whereas that due to storms was sudden, and the river subsided with almost equal rapidity. These storms were of frequent occurrence in May and June. During April the maximum rise was about 1 foot 6 inches, in May about 4 feet, and in June 5 feet. Rises, however, like these, combined with the rapid current, taxed the stability of the bridge very severely. On the 28th June the river rose about 7 feet, and a portion of the bridge was carried away.

5. *Rate of Current.*—The current was very rapid, and varied a good deal, being greater in some channels than in others, and even in different parts of the same channel; on the 7th April it was estimated as varying from 3 to 6 miles an hour. It increased considerably later on, reaching 8 or 9 miles an hour at times.

6. *Nature of Bed.*—The bed of the river consisted of round boulders, whose tendency to roll away at each rise added to the difficulty of maintaining the bridge.

7. *Material Available.*—The material for bridging purposes consisted of timber, obtained by demolishing a native fort and some villages in the neighbourhood. It was, however, of inferior quality both in size and soundness, and as it was impossible to pick and choose, a considerable margin of safety had to be given. That suitable for the trestles and road-bearers was about 15 feet long and 6 inches to 8 inches in mean diameter, while the doors of houses supplied material for the roadway.

8. *Method of Construction.*—The following general plan of the bridge was decided on:—

Piers.—One crate (or crib) filled with stones to every 3 or 4 trestles to give steadiness in the whole structure.

Trestles.—Two-legged, braced as usual, and strengthened by two props under the transoms (*Plates* IV. and V.).

Span.—A uniform span of 12 feet was adopted.

Roadway.—The width was limited to 5 feet 6 inches, as the doors available for use as chesses did not admit of its being made broader.

Road-bearers.—Four per span were, as a rule, considered sufficient.

The height of the roadway was fixed at 6 feet above the level of the water on the 8th April. This allowed for as much rise in the river as the bridge would stand.

9. *Trestles.*—The pattern of two-legged trestle adopted proved to be an excellent one of its kind, and it may be noted that, out of 80 trestles of this description, only one failed from structural weakness, and then only because the diagonal braces gave way. Many had to be replaced later on by four-legged trestles on account of the scour undercutting the down stream legs, but none actually broke.

10. *Crates.*—The crates (or cribs) proved rather weak, and required constant attention, as in some instances they were made without bottoms ; in three cases the scour of the water completely emptied them of stones in the course of a few hours. Owing to the short time available, they were rather too roughly put together, but under ordinary circumstances, when properly made, they add immensely to the stability of a bridge.

11. *Four-legged Trestles.*—The four-legged trestles used to replace any of the two-legged ones which had to be taken out owing to undercutting were of the pattern given in the accompanying sketch (*Plate* V.). They were made by joining a couple of the two-legged trestles securely together with wire lashings and braces, and then putting an extra transom on the top. If carefully made, and bolted instead of spiked, this forms a very strong trestle, and, given time and material, is preferable, for a river of this description, to the two-legged trestle.

12. *Officers and Men Employed on the Construction.*—The 4th Company, Bengal S. and M., under Major Aylmer, V.C., worked on the bridge from the 8th April until the evening of the 9th April, when Major Barton, R.E., was placed in charge of the work. The 1st Company, under Capt. Serjeant, and 6th Company, under Capt. Skey, assisted him from the 9th April until 16th April.

13. In addition to building the bridge, a large number of the sappers were employed in demolishing houses, stacking the timber obtained from them, also in making the approaches to the different portions of the bridge and the raised causeways between them. Hospital dhooley-bearers and local coolies were utilized in carrying the timber from the villages to the site of the bridge, and collecting stones for the causeways.

14. On April 14th there was no work on the bridge, as a large convoy of ordnance and other stores had to be taken over by coolies. But by the 16th April, or in 8 working days, the bridge was completed. It was opened for traffic the same evening, and a large convoy of pack bullocks crossed over it. The total length of the bridge was 1,350 feet, or 450 yards.

15. *Maintenance.*—This mainly consisted of replacing two-legged trestles by four-legged ones (often a matter of considerable difficulty in the rapid current) whenever this was rendered necessary by scouring, placing camel nets filled with stones on the upstream side of the trestles and crates to break the force of the current, and to prevent scouring, raising the transoms of any trestles that had sunk, repairing hand-rails, keeping roadway in order with fresh earth, grass, etc.

16. The bridge was never closed for the whole day; it was always open to the regular convoy. Repairs were carried out in the afternoon, and only occupied a few hours daily.

17. Major Barton left Chakdara on the 22nd April, and the maintenance was entrusted to Captain Skey from 22nd to 30th, with half the 6th Company, Bengal Sappers and Miners. Afterwards Captain Heath, assisted by a small detachment of the 6th Company, Bengal Sappers and Miners, took charge of it.

18. *Traffic.*—Captain Heath estimates the number of laden animals (mules, ponies, camels, and bullocks) that passed daily at somewhere about 3,000. Major Barton says:—"From my own notes, and those of Captain Heath, it will be seen that the bridge was open for traffic from the 14th April to 25th June, a period of 72 days, and if Captain Heath's estimate be correct, during this period some 200,000 laden animals crossed it, representing probably a maundage (1 maund = 80 lbs.) of not less than 600,000. A large number of unladen animals also crossed the bridge on their return journeys."

19. *Destruction of Bridge.*—A flood on the night of the 24th—25th June did so much damage to the bridge that the available labour was not sufficient for its repair, and it was decided to abandon it. It remained standing, however, through a very heavy flood on the night of the 25th—26th June; on the night of 27th—28th June 30 or 40 yards were carried away.

20. During the construction of the bridge, the troops, followers and baggage animals had to use the ford, which daily became more dangerous owing to the rise in the river, and to the smaller stones in the bed being displaced by the traffic and then carried downstream by the current, thus making the ford deeper.

21. *Attock Boatmen.*—The Attock boatmen, on their mussacks (inflated skins), were invaluable here. They are absolutely fearless of the water, however rapid it may be. They were stationed at intervals across the river; any man crossing who found himself in

difficulties had a boatman at his side in a moment, and animals wandering off the ford and floundering in the water were at once seized and brought back.

22. With the exception of two sepoys, who endeavoured to cross at an unauthorized place, not a single man or animal was drowned while fording the river.

23. Major Barton, with reference to these boatmen, writes:— "Had we not been able to avail ourselves of their assistance, I am convinced that the loss of life in crossing the river would have been considerable, and that of stores very great."

REPORT ON WORK DONE BY THE PONTOON SECTION, BENGAL SAPPERS AND MINERS, DURING THE CHITRAL RELIEF EXPEDITION, 1895 (*Plates* VI., VII., VIII.).

Mobilization.—April 11th.—Orders for the mobilization of the Pontoon Section of A Company, Bengal Sappers and Miners, were received at Roorkee on the morning of April 11th. The pontoons were then in bridge at Hurdwar on the Ganges.

Establishment.—The Section detailed for the expedition consisted of 1 Captain, 1 Subaltern (Lieutenant G. Boileau, R.E.), 3 British N.C.O.'s, 2 Native Officers, 61 rank and file, with 26 pontoons and equipment, carried on 38 wagons and 4 carts.

The above were dispatched in two trains, which left Roorkee on the evenings of the 13th and 14th of April, and arrived at Nowshera on the mornings of the 16th and 17th.

Transport by Rail.—April 13th to 17th.—The trucks supplied by the Oudh and Rohilkhand Railway were *end loading*, which much facilitated the entraining operations. The trains were marshalled in a continuous line of trucks in front of an end-loading ramp, built by the Royal Artillery, of gun skids and platform planks, and the pontoons loaded on their wagons were run intact from the ramp to their relative positions in the train. It was supposed that, owing to the length of a pontoon, it would be necessary to interpose a store wagon or an empty truck between every two pontoons, but this was not found to be the case; the trucks supplied gave about one foot of air space between the ends of two adjacent pontoons, which space was considered to be sufficient by the Traffic Inspector, and proved a safe allowance.

April 17th to 22nd.—Malakand Pass.—The road over the Malakand Pass was reconnoitred by the officer commanding the Section on April 17th, and it was considered that, with a little labour at certain bad places, it was passable for the pontoons, but with difficulty. A report to this effect was made to the C.R.E., Line of Communications, and on April 21st orders were issued for two pontoons and stores to be got over if possible. The whole of the pontoons had, however, been stopped at Nowshera by order; it was not, therefore, until the 22nd that the experiment could be made. On that day one pontoon and wagon were manhauled half-way up the Pass.

April 25th.—By the evening of the 25th, with the help of working parties from the 29th and 30th Punjab Infantry, six pontoons and their equipment had been got to the top of the Pass. The work was difficult, as in many places, owing to the narrowness of the road (track of wagons 5 feet 10 inches) and the weakness of the outer retaining walls, the pontoons had to be shouldered, and the wagons got over afterwards, while, in order to get round the bends in the road, the wagons had frequently to be bodily lifted, and the time available for work was restricted to from one to three hours daily, as the road was required for convoys.

April 26th.—On the 26th, with the help of a working party of 100 men from the East Lancashire Regiment, four pontoons were taken down the zig-zag to the Northern foot of the Pass. The road was extremely bad, the pontoons had to be shouldered and carried the whole way down, while the wagons had to be sent down in two pieces.

April 27th.—Arrival at Swat River Flying Bridge.—Four pontoons, with equipment, reached the Swat river at Chakdarrah, on the evening of the 27th, and on the morning of the 28th a flying bridge, working by a traveller on a steel wire cable, was established near the site of the suspension bridge.

Strength of Current.—The current at this place averaged nine miles an hour in the swiftest part of the stream, and with a little care, such as keeping all loads towards the stern of the pontoons, the flying bridge worked well and safely, and was in continual use, working daily from 6 a.m. to 8 p.m until June 8th (42 days), when it was no longer required, as communication had been established across the suspension bridge. Two accidents occurred, one from the breaking of a rope, and the other from mismanagement, but the raft was only temporarily stopped.

April 28th.--On the evening of the 28th orders were issued for the whole of the pontoons to be brought to the Swat river. Lieutenant Boileau went back to Malakand for this purpose, and by the 3rd of May sufficient pontoons had arrived to form a bridge over the larger stream. On that day a bridge was formed of 13 pontoons, about 50 yards below the site of the suspension bridge.

First Bridge.—May 4th to 7th.—On the 4th, more pontoons having arrived, the small stream was bridged with five pontoons, and on the 5th Lieutenant Boileau arrived with the remainder of the Section.

Second Bridge.—On the 6th the current increased, and it was considered advisable to shift the bridge lower down stream. A cable was stretched and an attempt made on the 7th to bridge where the current was slightly slacker, but while constructing the bridge two pontoons were swamped in the rough water, and the attempt was given up; the pontoons were recovered, but were badly damaged.

May 13th.—Present Bridge.—A fresh site was selected about half a mile below the suspension bridge, and was bridged by the evening of the 13th.

Strength of Current.—This bridge consists of 22 pontoons (345 feet), and 150 feet of trestle and crib work, joining up two islands to the main banks (*vide* sketch), the current here, when snow water was coming down, ran to eight miles an hour, but has probably run 10 miles an hour in times of flood; these, however, usually last only from three to five hours at a time.

Behaviour of Bridge.—This bridge, on the whole, has stood well, and, from the day it was established until the date of this report, has taken daily convoys, running to 3,000 animals in one convoy, with one exception, June 26th, when a heavy flood swamped two pontoons and cut off the approaches. On two other occasions pontoons were swamped, once by flood and once by crowded camels, but the damage was only temporary.

Suitability of Pontoons.—Defects.—Cracks in Copper of Bows.—Ribbing.—The pontoons, however, are ill adapted to stand the strain of strong currents; the copper of the bows, from the continued bulging in and out, occasioned by the varying pressure of the water, eventually cracks, and the pontoons in the swiftest part of the current have one or other been almost continually under repair, so much so that, had there been no spare pontoon (one was spare), the bridge would have had to be constantly closed while a pontoon was being taken out, mended and replaced, an operation of some hours. Pontoons taken out of bridge have been found with six, seven or eight cracks, varying from one to three inches long. It was found best to double plate the whole of the bows, if possible, but even this is not effective, as in several instances cracks have appeared through both plates. The only remedy appears to be a better system of ribbing, or a better form of bow (the instructional pontoons with raised bows have suffered very little, but they are not in the strongest part of the current).

Defective Balance of Pontoons.—The balance of the pontoons appears bad ; in strong currents they are so "down by the bows" that, in addition to a heavy weighting of stones on the stern, most uneconomical of floatation, it had been found necessary, for the sake of safety, to lash the up-stream ribands to the second baulk from the outside so as to keep the loads towards the stern of the bridge ; this, of course, has the disadvantage of reducing the roadway. The square stern of the pontoons is believed to be partly responsible for this defect.

Camel Net Breakwaters.—Camel nets, loaded with stones, and slung from a wire rope so as to hang three feet in front of each pontoon, were found to be of good effect as breakwaters, and as protection from logs. On one occasion a cask bridge, some yards in length, was swept on to the pontoons, and it was probably greatly owing to these nets that the bridge was saved from severe damage. These nets were, however, rapidly washed to pieces in a flood, and have since been replaced by nettings of wire.

Remarks.—The experience gained, first on the march up country, and secondly with the pontoons in bridge, suggests the following remarks :—

(1). *Portable Pontoons.*—That some sort of portable pontoon should be adopted, either the pattern existing at home, or a form of collapsible boat (the German army is, I believe, equipped with a large size of Berthon boat to carry loads up to siege guns).

(2). *Bows of Pontoons.*—If the copper pontoon is adhered to, its shape should be adapted to fast currents, and the bows should be considerably strengthened.

(3). *Combings.*—The combings of pontoons should be heightened.

(4). *Drill.*—In rapid water the pontoon drill for forming up is in one respect unsuitable ; on the word "baulks" only the two outer baulks should at first be placed, and the others got out gradually; this prevents crowding on the last pontoon.

(5). *Equipment.*—The remainder of the equipment can hardly be improved; the wagons especially have stood the rough work admirably.

Besides the work noted above, the pontoon section have built three trestle bridges, 70 feet, 130 feet, 160 feet respectively in length, and have assisted when required at work on the suspension bridge.

G. M. HEATH, CAPT., R.E.,
Commanding A Co., Bengal Sappers and Miners.

CHAKDARRAH,
15*th July*, 1895.

REPORT ON BRIDGE OVER SWAT RIVER (*Plates* IX. & X.).

General Description of River and necessity for Bridge.—The Swat river between the villages of Thana and Khar flows in a broad flat valley some $1\frac{1}{2}$ to $2\frac{1}{2}$ miles wide, and is divided in some parts into as many as five separate branches or beds, while in others it is confined to one or two. Very little was known regarding the course and nature of the river above the point where it enters British territory at Abazai before the Chitral Relief Expedition started. Observations at the head works of the Swat river canal showed that, as soon as the hot weather set in, snow water came down in considerable quantities, while later on, in July and August, floods rising to 9 feet at Abazai occurred after heavy rain. It was also known that a large quantity of timber (deodar) was floated down the river, and this was believed to come chiefly from the Upper Swat Valley. As a matter of fact, however, it seems probable that the greater part of the timber and a considerable portion of the snow and flood water comes down the Panjkora river, which joins the Swat river above Abazai, but below the point where it was crossed by the Chitral Relief Force.

After forcing the Malakand and advancing up the valley to Alladand and Thana, the Relief Force forded the river above the village of Chakdarrah, and the 1st and 6th Companies of Bengal

Sappers and Miners, assisted by Attock boatmen, at once proceeded to construct a trestle and crib bridge opposite Chakdarrah itself. At this point the river flows in five separate beds, with islands between, and the current is normally about 7 miles an hour.

The trestle bridge, a very substantial piece of work, was completed on April 17th, but it was felt that it would not be safe to rely on this one bridge as the sole means of communication across the river, especially as it was not known how soon it would be before the river rose to such a height as to imperil the bridge, or it became damaged by the logs which it was thought would soon be floating down in large numbers. It was accordingly decided to construct a permanent bridge raised to a safe height above flood level as quickly as possible.

Style of Bridge necessary.—As substantial piers could not be erected in the running water in the time available, the only alternative for bridging the wide branches of the river was to have one or more suspension bridges. After careful search a site was selected for the new bridge about half a mile below the trestle bridge. At this point the five branches crossed by the trestle bridge are united into two main branches, that on the left side being considerably the wider. Measurements were made of the widths of the waterway, and it was found that at that time—the middle of April—the left branch could be spanned by 250 and the right by about 100 or 110 feet. It was, however, obvious that a very small rise in the water level would very considerably increase the width of waterway, and that the island between the two branches, which was some 350 feet across, was completely submerged in flood time, and would have to be crossed at a high level with arrangements for a considerable waterway underneath.

These considerations led to the adoption for the bridge of two suspension spans, one of 250 feet for the left, and the other of 100 or 110 feet for the right, branch. In order partially to cross the island and to provide for the increase in the width of the waterway in flood time, it was decided to form back half spans for each of the suspension bridges; by this means the effective length of each suspension bridge was doubled, and the width to be crossed on the island about halved. The remaining intermediate space of 160 or 170 feet could easily be bridged with trussed beams resting on trestles, with one or two stone piers to give stability.

Materials for Piers.—For the 250 feet span it was obvious that there would be a difficulty in obtaining, locally, suitable timber for the piers. With a dip of $\frac{1}{12}$ and a camber of 3 or 4 feet, a height of 24 or 25 feet is required for the piers. It was known by this time that no deodar could be obtained from the river, and the only wood avilable in any quantity consisted of chir bullies up to 8 inches, which had to be carried several miles from the Laram Pass. There are a few mulberry and shishum trees near the villages, but all the fine specimens grow in graveyards, from which the Political Officers would not allow them to be taken, and the few logs required for anchorages, etc., were only obtained with the greatest difficulty. It was therefore decided that the uprights of the 250 feet span should be of angle irons suitably braced together.

Length of Iron Piers.—It was at first intended that the ironwork should be 40 feet high, of which 14 feet was to be built into the masonry and 26 feet to rise above the roadway. Each pier was to consist of two pillars joined at the top by cross bracing. Each pillar was made up of four angle irons $3\frac{1}{2}'' \times 3\frac{1}{2}'' \times \frac{1}{2}''$ forming a square with an 8 feet side at the bottom, where they were connected by horizontal angle pieces. These angle pieces sloped inwards at a slope of 1 in 12, making the dimensions 1 foot 4 inches square at the top, and the width between the two pillars at the roadway level, *i.e.*, 14 feet from the bottom, was fixed at 7 feet. It was also decided that the cables should consist of 3-inch flexible steel wire ropes, and it was roughly worked out that six of these would be required for each cable in the large span and two each in the small span. The cables were to be laid flat, *i.e.*, side by side, with clips at every 10 feet, the clips being provided with rings in the centre to which the $\frac{1}{2}$-inch round iron suspending rods could be hooked.

These preliminaries having been settled by the Commanding Royal Engineer, Lines of Communication, Lieutenant Rees, R.E., was on April 15th despatched to Rawal Pindi to arrange for the preparation of the ironwork, and meanwhile Lieutenants Duff and Walpole, R.E., who were temporarily in charge of the work, commenced the collection and dressing of stone for the piers.

On April 18th Captain G. Williams, R.E., who had been put in charge of the construction of the bridge, arrived at Chakdarrah and took over from Lieutenant Duff, R.E., who at once left for Panjkora, Lieutenant Walpole remaining with Captain Williams.

Length of Spans.—On laying out and measuring accurately the length of the bridge, it was considered advisable to make the smaller or right suspension span 110 feet, so as to keep the piers well out of the permanent stream, as the banks were sandy and liable to scour.

Loads to be Carried.—The orders for the bridge were to the effect that it was to be capable of carrying :—

(1). Infantry in single rank crowded.
(2). Camels and other pack transport.
(3). Field guns.

Of these loads the maximum stress is brought on the cables by the loaded camels, for the infantry load amounts to 140 lbs. (live) per foot run, while the camels give 15 cwt. = 1,680 lbs. over a length of 10 feet (*Instruction in Military Engineering*, Part III., page 6), or 168 lbs. per foot.

Taking the probable weight of the bridge at 130* feet per foot run, the total dead loads work out to :—

For large span :—

$$250 \times \left(130 + \frac{168 \times 3}{2}\right) = 250 \times 382 = 4{\cdot}26 \text{ tons}$$

For small spans :—

$$110 \times 382 = 18{\cdot}8 \text{ tons,}$$

and, taking the dip at $\frac{1}{12}$ in each case, the maximum tension in the cables is† :—

For 250 feet span :—

$$42{\cdot}6 \times 1{\cdot}58 = 67{\cdot}3 \text{ tons.}$$

For 110 feet span :—

$$18{\cdot}8 \times 1{\cdot}58 = 29{\cdot}7 \text{ tons.}$$

* *I.M.E.*, Vol. I., Part III., para. 176, gives 45 lbs. for a 100-foot span and 90 lbs. for a 200-foot span. This is very misleading, as each bridge is designed to take the same load (infantry two deep), and the weight of roadway per foot would be nearly the same in the two cases.

† *I.M.E.*, Part III., para. 175.

With 6 and 2 wire ropes in each cable, respectively, this gives a strain of :—

5·6 tons per 3-inch rope in the large span, and
7·4 tons per 3-inch rope in the small span.

Taking the breaking weight of a 3-inch flexible wire cable at 18 tons,* this gives factors of safety of 3·2 and 2·4 respectively.

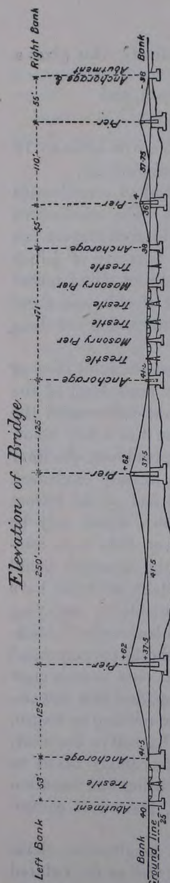
The extra strength in the large span was found of considerable value in preventing unsteadiness in the bridge. The calculations for the suspending bars and for the transoms and road-bearers are not given, as they are perfectly simple. The bars are of ½-inch round iron, the transoms are of deodar 6″ × 8″ or of chir 7 inches diameter, and the roadbearers, six in number, are of chir, and about 6 inches diameter. The transoms are 10 feet apart and 8 feet long between the suspending bars.

Level of Floor of Bridge.—It was proposed to put the road level of the bridge about 5 or 6 feet above the highest flood level of the water in the river. At the time the bridge was commenced the water level in the river was not more than some 3 or 4 feet below the flood level, for, owing to its being able to spread out, the river does not rise very much in time of flood. As already explained, the idea was to embed in masonry the lower 14 feet of the 40-foot long iron piers. But, as the road level, as shown, would only be some 8 or 9 feet above the water level in the river when work commenced, it was obvious that the lower end of the ironwork would have to be 5 or 6 feet below water level. This might, no doubt, have been very desirable had steam pumps been available for emptying the excavation ; but as nothing better than grass baskets was obtainable for clearing the foundations of water, and the latter percolated through the gravelly river bed very rapidly, it at once became clear that the excavations could not be taken very deep, and that the embedded portion of the ironwork would have to be reduced in length.

Reasons for reducing length of Iron Piers.—The Executive Engineer, Rawal Pindi Division, Military Works, was accordingly asked to reduce the piers from 40 to 34 feet in height, it being the intention to embed 9 feet of the 34, leaving 25 projected, instead of embedding 14 feet out of 40.

Elevation of Bridge.—In the margin is given a longitudinal elevation of the bridge, showing the various spans, as well as the reduced levels finally adopted for the roadway and the tops of the piers.

* *I.M.E.*, Part III., para. 22, gives 24·5 tons, but this is believed to be too high.



It will be noticed that in the 110-foot bridge there is a camber of 1 foot 9 inches, or 1 in 31, and in the 250 foot bridge, one of 4 feet, also 1 in 31, and that the back half spans have a similar rise from the piers. It was thought advisable that the half spans and the full spans should be symmetrical, so that the strain on the piers with equal loads should be vertical. As the form of anchorage adopted has a beam right across, the roadway had to rise, and passes over the beam, the top of which is protected with iron.

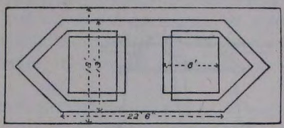
The water level is not shown on the section; it varies considerably in the two channels, and even in different parts of the same channel. In the channel near the left bank, that is, in the main channel, the water level is some two feet lower than in the smaller channel near the right bank.

The level of highest flood is extremely difficult to fix, as the testimony of the inhabitants is most conflicting and untrustworthy. As far as can be judged from the indications, the highest flood level is about R.L. 31·5 on the right bank and about R.L. 29·5 on the left bank. This gives a clear height of about 6 feet* at the centre of the small span, and of 12 feet at the centre of the large span. The greater height above floods over the main stream is necessary, as it is in the main stream that floating trees with projecting branches will come down in flood time.

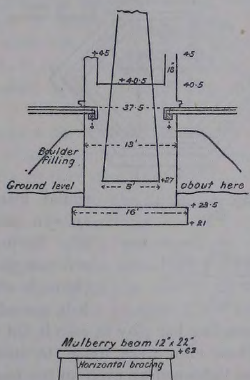
Details of 250 feet Span.—It will now be convenient to describe the different portions of the bridge in detail, beginning with the suspension bridge of 250 feet central span.

* As a matter of fact, the small span, for various reasons, sank a good dea more than the large span, and finally had a camber of about 9 inches only making the level of roadway at the centre about R.L. 36·75.

In a bridge with back half spans, in which the weight of roadway, etc., is considerably less than that of the occasional load, it was obviously necessary to fasten the cables on the tops of the pier, as otherwise they would slip over when one part of the bridge was loaded and the other parts were empty. At such a time there is a considerable overturning moment acting on the pier, and it was necessary to make the iron pillars themselves and the masonry base strong enough to resist this.

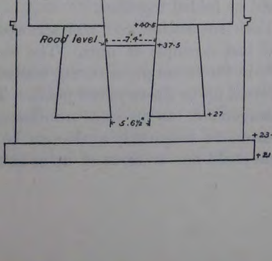


In the margin is given a plan and section of the piers of the 250 feet span.

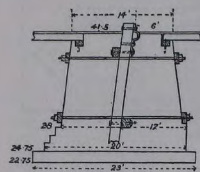


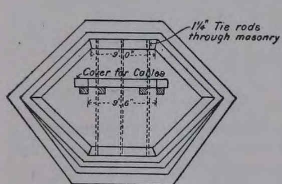
It will be seen that the ends of the piers were built up 2 feet 6 inches above the roadway level, in order to give greater stability, and an 18-inch parapet was built round them for defensive purposes.

In the margin are given a plan and section of the 250-foot span anchorages. The anchor beams consisted of mulberry logs, about 15 inches diameter, strongly bolted and strapped to a framework of mulberry or shishum wood 16 feet high, and of timbers about 10 inches square, the whole being built into the masonry, and



the roadway passing over the top of the anchor beam, which was faced with iron.

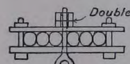




To strengthen the anchor piers in the case of the 250-foot span, six $1\frac{1}{4}$-inch round iron tie rods, bolted to mulberry timbers at each end, were built into the masonry, as shown in the drawings.

Suspending Arrangements.—As already stated, each cable of the 250-foot span consisted of six 3-inch steel wire ropes. They were laid flat side by side, and were clipped at 10-foot intervals by clips consisting of two $\frac{1}{2}$-inch iron plates bolted together. These clips also formed the point of attachment for the $\frac{1}{2}$-inch round iron suspension rods, a bolt with an eye passing through the centre of the clip, having three wire ropes on each side, *vide* margin. The holes in the $\frac{1}{2}$-inch plates, through which the central suspending eye-bolt passed, were slotted so as to give the suspending bar play in case it did not hang vertically.

Sketch of suspending Clip.



These clips were found to answer very well, and did not slip when tightened up even on the more sloping parts of the cables near the piers.

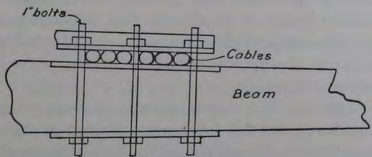
Suspension Rods.—As stated, the suspension rods were of $\frac{1}{2}$-inch round iron, and, seeing everything had to be brought up on camels, the longer rods were made with welded eye joints, so that they could be folded together.

Each suspension rod was screwed for 2 feet at the lower end, and had a couple of nuts. The end of the rod passed through a hole in the transom; a strong washer was then put on and the nuts screwed up to the required point. This is by no means a convenient arrangement, as it is a troublesome matter to raise or lower a transom as frequently as has to be done. It was found that the nuts could not be screwed up so as to lift the transom without first taking off the weight with ropes or wire slings. A better arrangement would be to have the suspension rods in two parts, screwed with male and female screws, and connected by a coupling placed at a convenient height. With this arrangement the transom can be raised or lowered without taking the weight off the suspension rod.

The upper ends of the rods were provided with a hook to engage with the eyebolt of the clip. The idea was that it would be convenient to hook the suspension rod in when constructing the roadway. As a matter of fact, the men at work on the cables found it very difficult to manipulate the long rods so as to get the hooks in, and found it easier to take out the eyebolt, hook it on to the rod, and then pass it through the clips and nut it up. The hooks were all strongly moused with wire, but proved a source of weakness when a number of camels fell down on the bridge, and subsequently the rods were attached to the eyebolts with welded eyes.

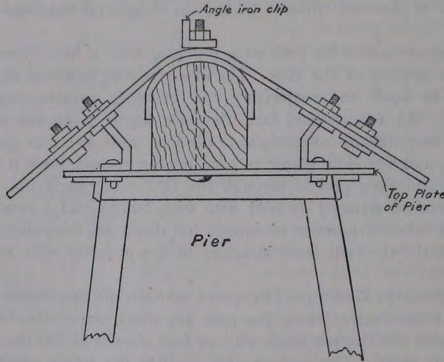
Cross Bracing (Vertical).—The spaces between the suspension rods, except at the centre, where the rods are short, were cross braced with double 600 lbs. telegraph wire, or four strands of 300 lbs. wire, twisted up tight. This undoubtedly steadied the bridge vertically, but it was troublesome to keep the bracing tight in the varying temperatures.

Clipping Arrangements at Top of Piers.—As already explained, it was necessary to clip the cables at the top of the piers to prevent their slipping under partial loads. For this purpose three 1-inch



bolts were provided passing through the centre of the wooden beam over which the cables passed, and a strong angle-iron clip was screwed down on to the cables, so as to grip them to the iron plate on top of the beam. Between the clip and the cables a lead washer was used. This arrangement was, however, found insufficient to prevent the cables from slipping, and the arrangement shown was adopted, and found to act successfully.

Fastening Arrangement.

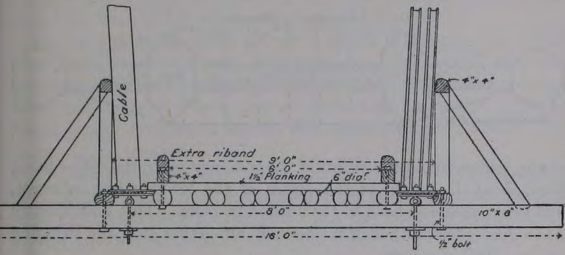


Fastening Arrangement.—The ends of each wire rope forming the cables were fastened off separately by taking a round turn round the anchor beam and clipping the running to the standing part with a modified form of the clip shown in *I.M.E.*, Vol. I., Part III., *Plate* XXI., *Figs.* 5—9. The modification of the clip chiefly consisted in omitting the small bolt passing between the cables, as shown in the text-book. It is obvious that this bolt must prevent the cup and wedges being tightened up and gripping the wire ropes. The modified form of clip was found to answer very well, three being used on each wire rope.

Roadway.—Attached is a section of the roadway of the bridge taken at the centre of the 250-foot span. Except at the centre, the transoms are only 10 feet long, the railing being fastened with wire to the $\frac{1}{2}$-inch suspension rods.

The outer roadbearers are laid in a continuous line, the ends being halved over the transoms so that the ribands which are bolted through to these roadbearers with $\frac{1}{2}$-inch bolts might also be in a straight line. The remaining roadbearers are laid overlapping on the transoms to which they are spiked.

In every six roadbearers one long one, reaching over two spans, so as to give the bridge stiffness, was included, but as hardly any

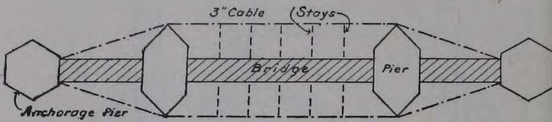


bullies over 20 feet long could be obtained, fished roadbearers had to be used for this purpose.

Railings.—The 3-foot 6-inch railing shown in the section has uprights 3 feet 3 inches apart, the spaces between being filled with cross bracing of 300lbs. wire twisted up tight. This forms a girder, which stiffens the bridge considerably under light loads, but is, of course, far too weak to do so when the bridge is fully loaded.

Movable Ends in 250-foot Span.—An important point in a long bridge with a considerable camber is that the ends of the road should be allowed free play to move back and fore as the curve of the bridge gets pressed down under the load. If this is not allowed for, *i.e.*, if the end roadbearers are spiked to the wall plates, the bridge comes into compression longitudinally under a heavy load, and this causes it to vibrate horizontally to an excessive extent. In the 250-foot span the ends of the end roadbearers pass through loops of $3'' \times \frac{1}{2}''$ iron fastened to the wall plates with coach screws.

Horizontal Swinging.—A great difficulty in the 250-foot span was to prevent horizontal swinging under heavy loads. Camels especially caused very considerable swinging, and they are very apt to fall if the movement is not checked. As will be seen from the plan of the bridge site, there were no suitable positions in which the usual up and down-stream stays could be fixed, as in flood time the piers are surrounded with water. An endeavour was made to provide anchorages by using large crates of wood filled with stones, but in heavy floods these showed signs of scouring and moving, and it was considered unsafe to stay the bridge to them. Accordingly, the bridge was steadied with wire stays, tightened by couplings, which were hooked on to 3-inch wire cables stretched tightly, on either side



of the bridge, round the points of the masonry piers, the cables being fixed about the height of the centre of the bridge when unloaded, and being anchored back to the anchorage piers. This undoubtedly has a good effect, although it does not altogether stop the swinging under a load of camels.

Protection of Foundations from Scour.—As already explained, it was not possible to take out the foundations of the masonry piers to a greater depth than 2 feet below the level of the water at the time of commencing work. As the main channel was at this time about 10 feet deep and running at about 7 miles an hour, it was obviously necessary to take steps to prevent the foundations becoming undermined by scouring. As will be seen from the plan, the pier in the most dangerous position is the right main pier, as in flood time it is exposed to the full force of two large branches of the river which meet just above it. In this case the pier was entirely surrounded by wooden crates, each 10 feet long by 5 feet by 5 feet. These were made of chir bullies (shishum, mulberry, or other hard wood not being available in sufficient quantities), and were fastened together and to one another with telegraph wire. The crates and the space inside them were then filled with boulders, forming an island 190 feet long and 44 feet broad round the pier.

This protected the pier satisfactorily for a time; but when heavy floods (which rose to the top of the crates) came down, the river bed was scoured out right up to the crates, and the boulders began to run out of them. To prevent this, long rolls of wire netting filled with stones—the rolls being $3\frac{1}{2}$ feet diameter—were placed along the front of the crates and were held in by pieces of wire cables carried back and fastened under the boulders forming the island. This had the desired effect, as the roll of stones could not be moved by the flood, and when scouring along it occurred, the roll dropped into the hole formed. Of course, such an arrangement can only be considered temporary, and if the bridge is maintained, the foundations should be protected in some more substantial way.

In the case of the other piers it was found sufficient to pitch well round the base, and between the piers, with stones.

On the left bank, which is very low and flooded at times, two long protective bunds were built to protect the bank forming the left approach to the bridge. The bunds are 6 feet wide at the top, have side slopes of 1 in 1, and are formed of alternative layers of boulders and brushwood mixed with earth and grass roots. This forms a good protective bank.

110-*foot Suspension Span.*—The details of the small suspension span are similar in most respects to those of the large span. The clips and suspending arrangements are the same, except that the former take only two cables instead of six.

The masonry of the piers and anchorages are very similar to those of the large span, the piers being 8 feet and the anchorages 12 feet wide at the top.

For the uprights of the piers no ironwork was ordered, as it was hoped sound wood would be obtainable. Unfortunately, owing to the prohibitions placed on the cutting of trees, shishum or mulberry scantlings of sufficient size could not be obtained, and it was found necessary to use chir bullies. These could only be obtained up to 8 inches in diameter, and were of inferior quality; and accordingly five were used dogged and framed together to form each side of the frame, the two sides being connected at the top by a mulberry beam over which the cables passed. Owing to the difficulty of getting wood, the piers are made as low as possible, and give a clear headway of 11 feet only, while $5\frac{1}{2}$ feet of the frame is embedded in the masonry.

Intermediate Spans.—The two intermediate masonry piers are 4 feet wide at the top. The wooden trestles are four-legged of the usual design, and the spans, which are 22 feet long, are crossed by four trussed beams. The latter consist of two deodar beams $6'' \times 6''$ fished together with 2 planks $7'' \times 2''$. There are two struts 2 feet long, and the tie rod is of 1-inch round iron.

Carrying out Work.—The only points to notice are—The 34-foot iron piers of the 250-foot span were put together *in situ* with the assistance of a derrick. The piers were made at Rawal Pindi, one pier consisting of two pillars, and the cross bracing being made in the workshops of the Executive Engineer Military Works, and the other in the North-Western Railway shops. The different shops of origin caused slight differences in the two piers and very considerable differences in marking the various parts. The ironwork was brought up by train to Nowshera, from thence to Dargai in carts, and from Dargai to Chakdarrah partly on camels and partly by coolies. Consequently, although every endeavour was made to forward the four pillars complete, parts of one arrived mixed up with parts of another, and there was some delay in sorting out the different members. In such cases the marking of the pieces should be very complete, as, though it may seem simple to fit the parts together in the shop, it may probably be difficult to do so at the site of the work. For instance, the base pieces of one of the pillars arrived and erection could have commenced, but there was nothing to show which side of the base faced the river, or which of the pillars was the upstream and which the downstream one; erection had consequently to be delayed until the remainder of the pier arrived and the relative positions could be traced by the numbering.

Cables.—The six 3-inch wire ropes forming each cable of the 350-foot span were strained separately and clipped together before being placed in position. Each cable weighed about 2 tons, and was hauled into position over the tops of the piers with tackles, attached to a 6-inch hemp hawser. A point to bear in mind is that precautions should be taken to prevent the twisting of the cable, owing to the tendency of the hemp hawser to untwist when the strain comes on it.

Materials.—The concrete in the foundations was mixed as follows at first:—

Mortar	1 part Portland Cement. 4 ,, sand.
Concrete	100 parts gravel. 35 ,, mortar mixed, as above.

The cement came chiefly from the old stock of the Attock Military Works Division. It was not quite of the best quality, and did not set very fast—and, as the bailing which had to be carried in on the foundations to keep the water down drew out a good deal of cement, the proportions in the mortar were increased to 1 of cement to $3\frac{1}{5}$ of sand.

As the bridge would have to be used directly the work was complete, *i.e.*, while the masonry was still green, the mortar in the masonry of the piers and anchorages was composed of 1 cement to $2\frac{2}{3}$ sand.

For ballast, pebbles of different sizes collected on the banks were used. Broken stone would have been more satisfactory, but there was no time to get up hammers, etc.

It may be useful to note that, when cement has to be carried on camels, it should be packed in tarred or water-proof bags, each holding half a cask. At first the cement was despatched to Dargai in casks by cart, and some delay was caused, as a cask of cement cannot be loaded on a camel.

The sand was sharp and of excellent quality.

The masonry was coursed rubble, the courses being from 5 to 7 inches deep. The outer face and the joints for 6 inches were chisel dressed; and the outer 18 inches of the piers were carefully built of roughly-squared stone, the interior being filled in with rough rubble and boulders.

The timber used was shishum and mulberry for the anchorages and tops of piers—chir for the roadbearers, hand-rails, ribands and piers of the small span, and for the transoms, deodar brought from Nowshera. All but the latter was quite green, and was obtained, specially the hard wood, with great difficulty, some of the trees having to be brought 3 or 4 miles across an irrigated country intersected with nullahs and without roads or paths.

Date of Commencement and Progress of Work.—The work was commenced on April 19th.

On May 4th the cement ran out and the concrete and masonry work was stopped till the 8th May, when a convoy bringing cement arrived.

The masonry was completed to the level of the bottom of the ironwork in the right main pier on May 1st and in the left main pier on May 3rd.

The ironwork of one pier began to arrive on May 3rd, but, owing to two of the angles of the base having been dropped by the camelmen in the Malakand Pass, the erection of the ironwork could not be commenced until the 12th May, when the missing pieces were found and forwarded.

The ironwork of the second main pier did not arrive till May 17th.

The erection of the ironwork of the right pier was completed on the 18th May and of the left pier on 22nd May.

The small span bridge was completed on 30th May.

Communication for foot traffic across the whole bridge was established by June 8th, and by the 14th June animals could cross.

The railings, etc., were completed by June 25th, on which date the up (loaded) traffic crossed the bridge.

It may be noted that the work was much impeded by the difficulty of communication across the river. All the building stone for the left bank had to be carried across the river. At first the only means of communication was by rafts of inflated skins and by cradles slung on a wire stretched across either branch of the river. On April 28th a cask pier bridge was completed across the small branch of the river, and on May 3rd a pontoon bridge was estab- shed across the main branch. On May 7th, however, the pontoon bridge had to be moved $\frac{1}{4}$ mile down stream to a part of the river where the current was weaker, and communication at the bridge site was carried on by means of a flying bridge consisting of two pontoons with superstructure. On Saturday, June 8th, a heavy flood came down, which carried away the cask bridge, swamped the approaches to the flying bridge, and sank two pontoons in the pontoon bridge.

Agency by which Work was carried out.—The work was carried out partly by civil and partly by military labour.

The following officers and subordinates were employed on the work,:—

Captain G. Williams, R.E., from commencement to completion.

Lieutenant. A. Walpole, R.E., from commencement to May 3rd.

Lieutenant F. F. N. Rees, R.E., from commencement to May 16th on preparation of and forwarding the ironwork, and from May 16th to July 12th at Chakdarrah.

Lieutenant C. Ainslie and 2nd Lieutenant W. Robertson, "Queen's Own" Madras Sappers and Miners, from 21st April to 26th June.

Sub-Conductor P. Hay, Military Works Department, from 24th April to 18th June.

Sergeant Sellens, Military Works Department, from commencement to 29th June.

The 6th Company, Queen's Own Madras Sappers and Miners, Lieutenant C. Ainslie, R.E., commanding, with the exception of small detachments at the Shahkot Pass and at Laram, were employed on the work from 21st April to 26th June.

The pontoon section of A Company, Bengal Sappers and Miners, under Captain G. M. Heath, R.E., assisted in completing the bridge, especially as regards wiring.

The civil labour employed included at one time 148 masons, 34 carpenters, and 12 blacksmiths.

G. WILLIAMS, CAPT., R.E.,
Field Engineer.

CHAKDARRAH,
1st *August*, 1895.

PANJKORA RAFT BRIDGE (*Plates* XI. and XII.).
CONSTRUCTED BY MAJOR AYLMER, V.C., R.E.

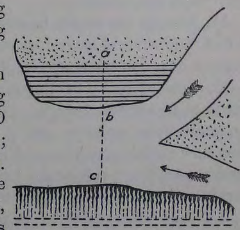
1. *Description of River.*—The Panjkora river is easily fordable in winter, but unfordable in summer. Its bed is sometimes half a mile broad, the water flowing in several shallow streams over a pebbly bottom; sometimes, as at the site of the suspension bridge, it flows through a narrow rocky gorge, and here is, except during excessive floods, barely 100 feet wide.

2. When the cavalry arrived on the 8th April, it was fordable, but, by the afternoon of the 11th April, the water had risen considerably, and the ford was considered unsafe, even for cavalry.

3. It was quite impossible to make a suspension bridge, which was plainly the best sort of bridge to make, as no materials had arrived in the way of wire. There were, however, a very large number of big logs lying in the river bed; many of these were 2 feet in diameter and 20 feet long.

4. It was determined that a floating bridge should be constructed with log piers.

5. The site chosen was as shown (see marginal sketch), *a*, *b*, *c*, being the position of the bridge. *a b*, 40 feet, was only about 6 inches deep; *b c*, 92 feet, was very deep indeed. Owing to the set of the stream, the current on the surface was not great, considering the small width. It was probably not over 5 miles an hour on the 11th.



Old Water Course.
Steep Hill Side.

6. On the evening of the 11th, the sappers of the 4th Company, Bengal S. & M., after a long day's work on the road, began to collect timber and float it down to the bridge site.

7. *Construction.*—Work was begun at 6.30 a.m. on the 12th. Working parties of British and native infantry brought road-bearers, chesses, doors of houses and all smaller timbers from Sado, some two miles above the site; two companies of the 23rd Pioneers assisted in collecting more large logs and in making approaches. The sappers, some 130 strong, were partly engaged in collecting timbers, and partly in making the bridge.

8. Each raft was composed of four of the biggest logs, 20 feet long and 18 inches to 24 inches in diameter. These were connected together with cross and diagonal pieces of timber as shown, fastened to the big logs by large spikes and wire. On these cross pieces were three transoms well secured by wire. These transoms were so placed that the roadbearers would not rest in the middle of the rafts, but several feet nearer the sterns, so as to raise the bows.

9. The rafts were placed at 15-foot intervals, and secured to iron jumpers, driven into the rock upstream, by wire and 3-inch manilla cables.

10. By the evening a rough roadway, suitable for infantry in single file, had been finished from *c* to *b*. There were five piers. Only two roadbearers had been put in, and the chesses were only very loosely secured. On the 13th, it was intended to make the roadway thoroughly good, build a causeway from *b* to *a*, and endeavour to raise the bows of the rafts, by a thin wire cable that arrived in the evening.

11. During the night, however, the river unexpectedly rose some 2 feet, and several large logs coming down struck the bridge. One log got over the bows of No. 2 raft and completely submerged it.

12. *Destruction.*—On the morning of the 13th an attempt was made to repair the bridge. No. 2 raft was cast off, repaired, and an endeavour made to get it into its place again, but the current was now running at about 10 miles an hour. Finally a 3-inch cable broke, and No. 2 raft broke loose and was wrecked half a mile down stream, the six men on it having a wonderful escape.

13. Just after this No. 3 raft got into a bad way, and it was decided to give up the idea of a floating bridge altogether.

14. The plates give necessary details of the bridge. It was intended only for mule transport.

DESCRIPTION OF SMALL SUSPENSION BRIDGE AT PANJKORA (*Plates* XIII., XIV., XV., XVI.).

CONSTRUCTED BY MAJOR AYLMER, V.C., R.E.

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1. On the morning of the 13th April, 1895, the log pier bridge over the Panjkora river was washed away, so it was determined to make a suspension bridge some two miles lower down.

2. The site was carefully examined and measured, the river being crossed on a mussack raft.

3. *Material Available.*—The only available material for the cables was telegraph wire. In the evening wood was collected and the construction of the telegraph wire cables and trestles was commenced. Work was carried on all night by reliefs.

4. *Construction.*—On the morning of the 14th April the trestles were carried down to the bridge site. The first thing done was to establish communication across the river by means of a seat secured to a block travelling along a tightly stretched 3-inch manilla cable. During the day footings were cut for the trestles, the anchors got into position and made secure, as hereafter described, and one trestle was raised.

5. On the 15th April the other trestle was put up, both trestles were stayed and strutted, the wire cables, which had been finished on the 14th, were got into position and secured to anchorages, slings and transoms were attached; by the evening foot passengers could go across, which they did, interfering greatly with the work. It rained for a great part of the day, making the fixing of slings and transoms a dangerous undertaking.

6. On the 16th the roadway was made thoroughly good even for camel transport, railings and side screens of bushes were put up, approaches finished and wind-stays fastened up and down stream to jumpers driven into the rock. Over 3,000 men crossed the bridge during the day, stopping the work for about three hours.

7. Infantry working parties assisted each day in carrying wood and stores, and in making approaches.

8. *Labour Employed.*—The average number of men employed daily for the 14th, 15th and 16th was :—120 sappers (4th Company, Bengal S. & M.), 150 infantry. Actual work on the bridge was from 7 a.m. to 6 p.m.

9. The bridge could have been finished by the evening of the 15th:—

(*a*). If the sappers had been camped at the site, instead of $2\frac{1}{2}$ miles off.

(*b*). If the weather had been fine. It was bad most of the time, especially on the 15th.

(*c*). If the work had not been constantly interrupted by the passage of troops when the roadway was incomplete.

10. This bridge had a constant and heavy traffic over it for two months. It was finally washed away, but not until the water had risen above the roadway.

Details of Construction.

Cables.—The telegraph wire used was supplied in bundles, suitable for mule transport. The wire had a breaking strain of 2,000 lbs. Each bundle gave about 440 feet of wire.

1. All the wire was properly unrolled as follows:—Each bundle was taken by two men, who attached one end of the wire to a tree, and then rolled the bundle along the ground and away from the tree (see *Fig.* 1, *Plate* XVI.). This is necessary, for if the wire is merely pulled off from one face of a bundle, there will be one twist in each length equal to the circumference of the bundle, and, when stretched, kinks, and a corresponding weakness, are produced.

2. It was settled to make the bridge with a span of 90 feet and dip of $\frac{1}{16}$. Taking the weight of the roadway as 60 lbs. per foot run, and the maximum distributed dead load as 210 lbs. per foot run, which is that for infantry in single file crowded, we get a maximum stress of 32,000 lbs., or 16,000 lbs. in each cable. It was thought best to have a considerable factor of safety, so 30 wires were put into each cable, giving a strength of 60,000 lbs.

3. After taking a careful section of the site, it was found that each cable would have to be 210 feet, allowing for fastening to anchorages. Instead of cutting the wire and making two cables, a single cable was constructed about 430 feet long. This saved time.

4. To construct the cable, seven of the unrolled wires were attached to a tree A. Another holdfast, B, was made at a distance of 430 feet. One of the wires was now taken, and a rope attached to its free end. Ten men, having stretched this wire as tight as

possible, made it fast to B holdfast by walking round it a couple of times, keeping the strain (see *Fig.* 2, *Plate* XVI.). In a similar way the six other wires were stretched.

5. Now, beginning at A, the seven wires were bound into a group with twine at every foot (see *Fig.* 3, *Plate* XVI.). The wires were not allowed to ride anywhere. Similarly three other 7-strand cables were made.

6. The main cable was then made by stretching the four 7-strand cables and two single wires, and binding them together with string at every 3 feet.

7. *Trestles.*—For details, see *Fig.* 2, *Plate* XV. The wood used was common pine. The standards had a minimum diameter of 10 inches. They were tenoned at the thin ends, and morticed cross-pieces were then fastened to them by iron straps 2 inches wide and $\frac{3}{8}$ inch thick, serving as a resting place for the cables. These trestles were so constructed that the roadway might pass a considerable height above the feet of the standards. They were put together at the site and erected entire, being strutted up and down stream, as well as in shore. They were also tied back to the anchorages, and were given a slight inclination in shore to allow for the tightening of the ties when the strain came on the cables.

8. *Anchorages.*—Both consisted of 14 foot logs 15 inches in diameter. That on the left bank was placed in a depression in the solid rock. Jumpers were driven down in front of it, and the whole was weighted down by some 4 or 5 feet of stonework above it. That on the right bank was placed behind a convenient shoulder of rock as shown.

9. *Placing Cables.*—One end was first fastened to one side "a" of the anchorage on the right bank by passing it twice round and binding the free end to itself, as shown in *Fig.* 8, *Plate* XVI. The cable was then placed over the two trestles, "b and c," and fastened n a similar manner to one side, "d," of the anchorage on the left bank, then taken to the other corner, "e," of the same anchorage and fastened as before, the free end being then led over the two trestles back to the anchorage on the right bank and secured to the end "f" of the log remote from the place where it was first attached (see *Fig.* 7, *Plate* XVI.). This was done so as to leave the cable between the trestles hanging on both sides with a dip of $\frac{1}{13}$.

10. *Construction of Roadway.*—The length of the slings by which the transoms were hung from the cables were calculated *vide* para. 178, Vol. I., Part III., *Military Engineering*, and an allowance made

in their length for a camber of 1 foot 6 inches. To the length so calculated was added a constant of 1 foot 6 inches for depth of transom, roadbearers and chesses. The slings were made by stretching and binding together three strands of wire. This was then bent in the shape shown (*Fig.* 9, *Plate* XVI.).

11. The slings were fixed as follows:—A thin beam, with rope ladders hanging from either end, was placed on the main cables near the trestles. The bottoms of the ladders were connected by a stout board so that men could stand on it. The beam had also ropes attached, so that it could be pulled backwards or forwards (*Fig.* 10, *Plate* XVI.). Two of these cradles were used simultaneously, one at either end of the bridge.

12. To fix the slings, two sappers, each taking a sling, stood on the board connecting the rope ladders, and were pulled out some 11 feet. Each sapper then fixed his sling by turning the ends a couple of times round the main cables, and then three or four times round the slings themselves (*Fig.* 11, *Plate* XVI.). The first two slings were tied back to the trestle to prevent them slipping forward.

13. The first pair of slings being fixed, transoms were placed in the loops and secured. A pair of roadbearers were then lashed to the transom, and a rough temporary roadway made with a few chesses (doors).

14. In practically the same way the roadway was made throughout; after being completed in this rough manner the bridge was carefully inspected and any error in the length of slings corrected.

15. The roadway was then finished off. There were four 6-inch roadbearers, generally covering two bays. The roadbearers were spiked to the transoms. The chesses were made of doors from native huts in the neighbourhood, ribands were well racked down, breaking joint with the roadbearers. Railings were added as shown in the section, and to these were attached branches and bushes, forming a screen so that animals should not be frightened at the rush of water below.

16. The chesses were covered with leaves and earth. Side stays were added up and down stream to prevent lateral motion, being secured to jumpers driven into the rock.

17. On the right bank, in shore from the trestle, the roadway was supported on two small trestles and a small crib pier.

18. For other particulars of this bridge see plates.

REPORT ON PANJKORA RIVER SUSPENSION BRIDGE (*Plates* XVII. and XVIII.).

Erected by Captain Serjeant, R.E., and 1st Company, Bengal S. & M., April, 1895.

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1. *Collection of Materials.*—1st Company, Bengal S. & M., marched from Chakdarrah to Panjkora river on 18th April, over Katgola Kotal and through Sado. On the following day a small party went up the river to look for suitable timber for the main frames. The C.R.E. had previously chosen a site for the bridge where the span was approximately 200 feet, rocks on either bank giving footings for the main frames, and allowing about 25 feet for the roadway above the water at the time. The dip of cables was fixed at $\frac{1}{12}$, and allowing for a camber of 2 feet and for the centre transom of the bridge to be not less than 2 feet below the main cable, the main frames had to be about 20 feet high. None of the wood taken out of villages and forts in the neighbourhood was considered of sufficient scantling or sound enough for these, so that logs had to be found and sawn up for the purpose; in fact, with the exception of some of the side struts of the main frames, and a few doors used for chessing, the whole of the wood used in the bridge was sawn from logs taken out of the river. The logs were warped down by Nowshera boatmen to a convenient position about 300 yards above the bridge, where they were landed and sawn up.

2. *Construction.*—On the 20th April a party was detailed to commence stretching the strands of telegraph wire for the main cables, on the principle described in Major Aylmer's *Notes on Bridging.* Each cable was made up of 84 strands of telegraph wire (300 lbs. to the mile, breaking strain of each wire 1,000 lbs.), the several wires being uniformly stretched by a party of 10 men and secured to holdfasts. The wires were then bound up in bundles of seven with twine at intervals of about 9 inches, care being taken to prevent strands overriding. For this purpose a rough gauge of wire twisted in loops was used, and run along as the binding pro-

gressed, keeping each wire in its proper relative position. The bundles of seven were subsequently bound up into one cable in a similar way, wire bindings taking the place of twine. Each cable, when complete, weighed about a ton.

3. The excavations for anchorages were commenced the same day. On both banks rock was met with, and considerable blasting had to be done before sufficient depth was obtained. The excavation on the left bank could only be taken back about 42 feet from the main frame, as the ground rose very steeply beyond this. The rock met with was very hard; a kind of trap. A depth of 5 feet was excavated below the natural ground, and the anchorages, which consisted of logs 18 feet long by 20 inches diameter, were placed in position. Holes were jumped immediately in front of the anchorages, and steel crowbars were placed in these, the whole was then very carefully built in with stones, pieces of wood being placed at intervals to bind the stones together into one mass.

4. *Main Frames.*—The sapper artificers and all sawyers were meanwhile engaged in making the main frames, and cutting up logs for roadbearers and chesses. The details of main frames are shown in *Plate* XVIII. The transoms were morticed on to the standards, and broad straps of iron were bolted on to take the main cables. A headway of 11 feet was allowed. The main frames were allowed to pivot at their base, and rested on broad bearing plates of wood, into which they were slightly recessed; they were prevented from moving forward by jumpers driven into the rock immediately in front of each standard. The frames were erected on 23rd and 24th April. The tackle for the left bank frame was fixed to a rock on the water's edge about 50 feet in front of the footing of the frame, the rocks on this side being only covered with water when the river is in flood. The tackle for erecting the right bank frame had to be secured on the far side of the river, as rocks fell almost vertically down to the water below the footings. The frames were raised in the usual way, back struts were fixed as shown in *Plate* XVIII., the frames being slightly set back from the vertical. The back guys were then secured to the anchorages. They consisted of $1\frac{1}{2}$-inch steel wire cable, subsequently supplemented by cables of 14 strands of telegraph wire (300 lbs. to mile).

5. *Fixing Cables.*—On 26th April the main cables, which had previously been placed in position in prolongation of the line of bridge, were passed over, one at a time. A 3-inch rope was attached to one end of the wire cable, and to a block and tackle on

the opposite bank. The cable was then slowly paid out over the top of the main frame, every precaution being taken to prevent it touching the water. The stream was so strong that the cable would have probably become unmanageable if it had once gone into the water, or, at any rate, would have been liable to be damaged against rocks, etc. Accordingly, when about $\frac{1}{3}$ of the cable had been passed over, a preventer block and tackle was fixed on the paying out side to prevent the cable taking charge. The cables were then secured to the anchorage with two round turns, the spare ends being twisted round the standing parts and securely bound with wire at every 9 inches. It was much less difficult than was anticipated to take the two turns round the anchorages. The cables were fixed about 5 feet higher than their permanent position, to allow for subsequent stretching, etc., when the load came on. Late the same evening, two 3-inch steel wire cables arrived. On the following day these were put up alongside the telegraph wire cables, and at the same dip. The roadway was then started, and as each transom was got out and slings fixed, the two cables were securely bound together with wire at intervals of about a foot.

6. *Slings and Roadway.*—The slings for transoms consisted of 8 strands of 300 lbs. telegraph wire. The length for each transom was calculated, and the wire bent over the hooks at exact length, measured from top of transom to bend of the hook, as calculated. Each transom was prepared on the banks and slings ready fixed, so that it was only necessary to hook the wires over the main cables, pass the transom out to its right interval, and secure. The return of the hooks was passed twice round the main cable, and the spare ends then twisted round and round their own standing ends, and bound with fine wire. The details of the rest of the roadway are shown in *Plate* XVIII. Sloping struts, from the foot of the main standards to the top of the first sling, were added to take the strain off the first two bays and to lessen motion. Wind ties were then fixed at every alternate transom and secured to jumpers driven into rocks on the banks. Diagonal wire braces of 7 strands of wire, as shown in *Plate* XVIII., were added to help take the strain off the vertical slings. The bridge was completed on May 1st.

7. *Men Employed.*—The actual number of men employed cannot be stated, as all spare men were employed on the approaches to the bridge; a party of about 15 men was employed daily sawing timber, and on an average, from 30 to 40 men on the rest of the bridge.

Materials Used.—The following is a general idea of materials used:—

Main standards ...	... 19′ × 12″ × 15″	...	No. 4
„ transoms ...	... 13′ × 12″ × 15″	...	„ 2
„ ledgers ...	... 11′ × 8″ × 5″	...	„ 2
„ diagonals ...	... 15′ × 8″ × 4″	...	„ 4
„ struts ...	... 16′ × 8″ × 6″	...	„ 10
„ „ ...	... 27′ × 8″ × 7″	...	„ 2
Ground plates ...	... 15′ × 15″ × 5″	...	„ 2
Transoms... ...	... 10′ × 9″ × 8″	...	„ 23
Roadbearers ...	... 18′ × 7″ × 6″	...	„ 48
Chesses	... 8′ × 12″ × 2″	...	„ 200
Ribands and hand-rails ...	18′ × 4″ × 3″	...	„ 48
Anchorage logs ...	... 18′ × 20″ diameter	...	„ 2
3″ steel wire cables (about)	400 feet ...	...	„ 2
Telegraph wire (about) ...	... ...	...	20 miles
Wire for binding ...	... ...	...	150 lbs.
1½″ steel cable for back guys (about)	...	..	500 feet
Screws 4″ ...	... ...	...	6 gross
Spikes 12″ ...	... ...	..	200 lbs.
Twine for binding ...	... ...	...	40 lbs.
Crowbars and jumpers for anchorages	...	...	No. 10

REPORT ON THE JANDUL RIVER BRIDGE (*Plate* XIX.).

CONSTRUCTED BY LIEUT. KEMP, R.E., AND THE 6TH COMPANY, BENGAL S. & M.

1. The trestle and crib bridge over the Jandul river (at first called the Ushiri) was commenced by the left half of the 6th Company, under Lieuts. Kemp and Halliday, on Saturday, 4th May, 1895.

2. *Site.*—The site was that chosen by Major Ellis, R.E., about half a mile above the junction with the Panjkora river, and 50 yards above the present ford.

3. *Nature of River.*—The water of the Jandul at the time was about 100 feet broad, its maximum depth 2 feet 6 inches at the

point of crossing; the current ran at $4\frac{1}{2}$ to 5 miles an hour over a shingly bed, the boulders being small, not averaging much more than half a cubic foot; where the bed was dry there was a deposit of 6 inches to 12 inches of fine sand on the right bank. Close to the right bank there was a small collection of smooth rocks slightly higher than the rest of the bed of the river. The total breadth of the river is about 230 feet, the banks on each side being of loam, 8 feet to 10 feet high, the right sloping $\frac{1}{1}$ and the left $\frac{2}{3}$.

4. *Nature of Bridge.*—The bridge was 240 feet long, divided into 20 spans of 12 feet, one crib between 4 trestles, giving a total of 3 cribs and 16 trestles (*Fig.* 1, *Plate* XIX.). The clear waterway allowed was 8 feet to the bottom of the road-bearers, the level being taken from the surface of the water, so that in some places 10 feet 6 inches depth of water was provided for. The width of the roadway was 5 feet 6 inches.

5. *Construction.*—The building of the bridge for the first three days progressed rapidly, as the timber used was that floated down the river by Lieut. Fowler, R.E., having been obtained from dismantling the fort at Mundah; after this the only timber that could be procured was that obtained by sawing up the deodar logs floating down the Panjkora. About half the bridge material was obtained from the scantlings floated down from Mundah, but about 120 feet of roadbearers, 6 trestles, and 140 chesses had to be sawn.

6. *Trestles and Cribs.*—The trestles were of the same description as those in the Swat trestle bridge, having 2 ledgers, and the diagonals meeting under the centre of the transom (*Fig.* 2, *Plate* XIX.). The scantlings were about $7'' \times 8''$ for uprights, $8'' \times 8''$ for transoms, $5'' \times 4''$ and $4'' \times 4''$ for ledgers and diagonals. The average size of the roadbearers was $6' \times 7''$ or 8 inches diameter, four being allowed for the roadway. At least half these were of sawn scantlings; the two outer ones were spiked to the transoms, and the inner ones tied with wire, to facilitate the substitution of new ones, if necessary.

7. The chesses were some of old doors, about 5 feet 6 inches long and 2 inches thick, and varying in width from 2 feet to 9 inches; the remainder were sawn 2 inches thick, 5 feet 6 inches long, and 10 inches wide. Over the chesses was a 2-inch layer of grass and rushes, and above this 2 inches of earth and sand.

8. The hand-rail was formed of thin scantlings, the supports being sloped slightly outwards, to give greater width for mule loads, and strutted, height 3 feet above roadway.

9. The cribs were 6 feet wide at bottom and 3 feet 6 inches at top, formed chiefly of small scantlings floated down the river; as two of them were built on the dry bed, or in only 1 foot of water, they were put together in their places in line with the trestles. Each trestle and the frames of the cribs were let down about 1 foot in the sand or shingle until they found a sound bottom on rock or large shingle, and heavy stones were piled round their feet.

10. *Approaches.*—The approaches were practically level with the roadway of the bridge, small cuttings and embankments were necessary at the shore ends, and the road was curved slightly northwards on both sides to meet the line of the bridge.

11. *Number of Sappers employed.*—The bridge was begun on 4th May by the left half of the company, numbering 66 men all told; on the night of the 4th the right half company arrived at Panjkora, and their carpenters and sawyers were employed, but beyond this no addition was made to the number of men. The average number of sappers was 60, including carpenters and sawyers per day, and the total number of days for the work 7, but, if suitable timber could have been found on the spot, the time would probably have been reduced to 4 days.

REPORT ON BRIDGE OVER USHIRI RIVER AT DARORA (*Plates* XX. and XXI.).

I received orders on 26th June, 1895, to proceed to Darora and improve the existing bridge, making the approaches fairly easy for mules; also to work on the road to the south.

The 1st Company, Bengal Sappers and Miners, marched to Darora on the 27th June. The approaches to the bridge were very bad on either side, and the bridge itself was very shaky, several mules falling into the river. The 34th Pioneers, who were marching immediately behind the 1st Company, were only able to get one wing over by dark.

Owing to transport being passed over, no work could be done on the bridge or its approaches the following day. The bridge was of the ordinary native cantilever type—span 66 feet, height of roadway above water 15 feet, depth of water in deepest channel 5 feet. The piers on either side were built of rough stone with wooden binders, that on the left bank being built up on an over-hanging rock; both were much out of repair. The centre span consisted of two 45-foot timbers, about 12 inches diameter, and $3\frac{3}{4}$ feet apart. They were supported on three timbers about 32 feet long, projecting 12 feet beyond the piers, these being in their turn supported by four similar timbers projecting about 6 feet, the shore ends being well weighted with stones. The flooring of the bridge was of the roughest hewn planking, with a plaited willow-twig riband. There were irrigation channels about 5 feet wide and 30 feet from either pier, the water from which was constantly cutting away the piers, and making the approaches to the bridge quagmires. The channel of the river towards the right bank was comparatively shallow and protected by rocks up stream, the main force of water being towards the left bank. There was a large rock almost in the centre of the river (*Plate* XX.) and immediately above the bridge.

As my first orders were to have the bridge ready for mule traffic in 15 days, I started making a crate of square timber ($5' \times 10'$ at top inside dimensions, $7' \times 11'$ at bottom), each piece being spiked to the uprights ($7'' \times 6''$), and all being firmly bound together with telegraph wire. The crate was placed in position on July 3rd as nearly as possible in the centre of the river, and immediately below the rock above referred to. It was securely anchored to this rock with jumpers, one about water level, and another 3 feet higher up.

The crate is shown square (*Plate* XXI.), but owing to the bed of the river being uneven, it did not settle down quite straight, but had a list towards the deeper part. The footings of the crate were excavated till shingle was reached, and the whole was filled in with large boulders. A frame was next made 10 feet high (standards $10'' \times 8''$) and braced in the usual way. This was erected on the top of the crate, and forced up, till it took the whole of the sag off the centre roadbearers, and practically stopped all motion in crossing the bridge. Two transoms, $8'' \times 7''$, were then lashed to these roadbearers, halfway between the centre frame and the piers, and sloping struts were placed as shown in the plate, butting against the transoms. These struts were subsequently connected by ledgers and transoms, and were braced in the usual way; wire ties were taken from the centres of the struts butting against the centre frame over the top of the centre frame. A rough frame was made on the right bank to take the feet of the struts; this was anchored back with wire to the original masonry pier, and the foot was further protected with a small crate of stones, all securely bound together with wire. The old flooring of the bridge was removed, and new chesses, $6\frac{1}{2}' \times 2'' \times 12''$, were put down. Owing to the massiveness of the existing roadbearers a third roadbearer was not considered necessary. Three subsidiary roadbearers were placed from shore transom on either bank, butting against the centre roadbearers, so as to make one continuous roadway, and to eliminate the step on to the centre span which existed in the old bridge. The bridge was completed in this way, with hand-rails, etc., by July 15th.

Owing to reports of the natives that in high floods logs came floating down, I started on July 16th to collect timber for the main frames shown in *Plate* XXI., the idea being to take the weight of the main roadbearers by wire ties passed over these frames and anchored back on shore. The frames were made as shown in the plate, and erected on wooden foot-plates about 4 feet from the edge of the pier on either side. Owing to the irrigation channels, it was impossible to get the anchorages as far back as was desirable. Logs about 13 feet long and 12 inches diameter were used for anchors, and were sunk 5 feet in the ground. The frames were strutted as shown in *Plate* XXI., and tied back to the anchors with 7 strands of (300 lb. to mile) telegraph wire. Two transoms, $9' \times 10'' \times 8''$, shown as *a* and *b* in the plate, were roughly lashed to the roadbearers, dividing the length of roadbearers into three parts of 15 feet each. The ties, which consisted of 21 telegraph wires bound up together in bundles of seven, were then passed over the main frames and round the two transoms. A round turn was taken round each anchor, and each tie was hauled taut by a tackle fixed at both ends. Hand-rails were subsequently fixed.

The object of the above arrangement of ties was that in case the centre crate got shifted in a flood, the centre span would still remain supported at *a* and *b* by the ties, even if the whole sub-structure got washed away. There was no connection between the sub-structure and the rest of the bridge, so that its collapse would not affect the bridge itself.

The bridge was finally completed on July 26th. There was some difficulty in obtaining wood near at hand. All had to be taken from the Panjkora river, as there was none in the Ushiri itself.

A photograph of the bridge is attached (*Plate* XX.).

The following is a rough list of materials used in the bridge :—

Main standards	$17\frac{1}{2}' \times 12'' \times 10''$	... No.	4
,, transoms	$12' \times 12'' \times 10''$	... ,,	2
,, ledgers	$9' \times 10'' \times 5''$	... ,,	2
,, diagonals	$13' \times 10'' \times 5''$	... ,,	4
Ground plates	$15' \times 12'' \times 6''$	... ,,	2
Main struts	$16' \times 8'' \times 6''$	... ,	4
Crate standards	$10' \times 7'' \times 6''$	.. ,,	4
,, webbing	$13' \times 4'' \times 4''$	... ,	20
,, ,, ...	$8' \times 4'' \times 4''$	... ,	30
Centre frame standards ...	$10' \times 12'' \times 8''$	... ,,	2
,, transoms ...	$8' \times 12'' \times 8''$	... ,,	1
,, ledger ...	$8' \times 10'' \times 5''$	... ,,	1
,, diagonals ...	$13' \times 8'' \times 5''$	... ,,	2
Sloping struts	$18' \times 8'' \times 7''$	... ,,	8
Ledgers and transoms for do.	$8' \times 7'' \times 4''$	... ,,	8
Bracing for do.	$15' \times 5'' \times 4''$	... ,,	8
Horizontal ties	$16' \times 6'' \times 4''$	... ,	8
Subsidiary roadbearers ...	$15' \times 7'' \times 6''$	... ,,	6
Chesses	$6\frac{1}{2}' \times 12'' \times 2''$	... ,,	70
Ribands and hand-rails ...	$16' \times 4'' \times 3''$	... ,,	22
Anchors	$13' \times 12'' \times 12''$	... ,,	2
Wire (300lb. to mile) (about)	... ...	... lb.	800
,, (75lb. to mile) (about)	... ...	... ,,	100
Spikes, 7 inches (about) ...	... ...	... ,,	150
Screws, 4 inches	... ...	... grs.	$\frac{1}{2}$
Twine, country	... ...	. lb.	15

J. R. B. SERJEANT, CAPT., R.E.,
Comdg. 1st Company, Bengal Sappers and Miners.

DARORA,
27th July, 1895.

REPORT ON BRIDGE AT CHUTYATAN
(*Plates* XXII. and XXIII.).

BUILT BY THE 1ST COMPANY, BENGAL SAPPERS AND MINERS, JUNE, 1895.

The Company marched to Chutyatan on June 6th, about 5 miles from Dir, with orders to repair the existing bridge and make the approaches to it on either side. The old bridge was of the ordinary cantilever pattern, but was in such a state that it was scarcely fit for single foot passengers: one side had sunk down over a foot owing to one of the only two roadbearers having half snapped across, and the planking was prevented from sliding off sideways by stones laid along above the sound roadbearer. It was at once evident that this could not be repaired. At the same time, it was necessary to keep it up till the new bridge was made, as this formed the only communication from bank to bank.

The company meanwhile worked on the right approach from the Bandai-Dir road, making a road 10 feet wide at an average gradient of $\frac{1}{12}$, waiting for further orders about the bridge.

On Monday, June 10th, I received orders from Commanding Royal Engineer, Lines of Communication, to erect a suspension bridge, as I had suggested, and I at once started all available sawyers collecting logs from the river and warping them down near site of bridge. It was a little difficult getting the wood from the river, as it had been jammed up among rocks, and there were only places here and there where logs could be landed and sawn up.

On June 11th I started the anchorages: 40 feet back from the foot of the standards the right bank was in loam and easy work; the left anchorage was all in rock, and took considerable blasting. I found there was just room to erect the bridge alongside (below) the existing one: there was a width of only just 10 feet on the left bank, measured from the timbers of the old bridge to the edge of the rock, so that it was a little trouble erecting the main frame this side, and ties had to be used up and down stream in place of side struts to steady the main frame when raised.

The main cables were pieces of 3-inch steel cable, about 35 fathoms each, which had been cut off as surplus from the cables used in the Panjkora bridge. One of these pieces seems of a very much better quality than the other, for no reason that I can see.

On 13th June the company started working on the left bank approaches, about 16 men being employed daily sawing, and carpenters making the frames, and 6 or 8 men on the left bank anchorage.

On June 17th the right bank frame was erected and backguys and struts fixed, and the following day the left bank, which, as already stated, gave a little trouble owing to the site being so cramped, the men having to stand on the very edge of the rock, 20 feet above the water, while raising the frame.

On June 20th the transoms were all got out, and communication effected from bank to bank. I fixed all the vertical slings to the transoms *before launching them out*, passing them through iron clips underneath the transoms, and measured the slings accurately (from previous calculation) on the bank, and bent the spare ends over in form of hooks, so that it was only necessary to hook these over the main cables and pass the transoms out to their proper interval—in this case 6½ feet. I found in this way it was scarcely necessary to adjust the length of any sling after getting out all the transoms. Diagonal bracing to assist the vertical slings was added, the braces passing under the transoms through the iron clips. Wind ties were subsequently fixed to every second transom, and fastened to jumpers let into the rock on either bank up and down stream. These were tightened with Spanish windlass so as to reduce lateral motion as far as possible.

The following is a list of all the principal materials employed :—

4	Standards	16′ × 12″ × 12″.
2	Topsils	13′ × 12″ × 12″.
4	Diagonals	15′ × 6″ × 5″ for bracing main frames.
2	Ledgers	11′ × 6″ × 5″ allowing headway of 9′ 6″.
4	Backstruts	16′ × 8″ × 5″.
2	Shore transoms	13′ × 15″ × 6″ for feet of standards.
2	Anchorages	logs 16′ × 15″ diameter.
11	Transoms	7½′ × 7″ × 6″.
24	Roadbearers	15′ × 9″ × 7″.
80	Chesses	6′6″ × 2″ × 12″.
12	Ribands	15′ × 4″ × 3″.
12	Hand-rails	15′ × 4″ × 3″.
2	Cables 3″ steel wire about 35 fathoms each.	
20	Bundles of telegraph wire (say, 2½ miles) 300 lbs.	
100	lbs. fine wire for binding.	
6	Jumpers for anchorages, footings, and windguys.	
2	Gross 4″ screws for fixing cheeses.	
158	Spikes, 10″.	

Average Number of Men, say 30, Daily Working at Bridge.—The number of men actually employed on the bridge cannot be stated, as all spare men were working on the approaches. Two sections (about 40 men) were employed raising the frames, and 1 section laying the roadway, half working from each bank, and a party of 12 to 15 men were sawing each day. The bridge was open for traffic on 22nd June, and the old bridge was dismantled, as it had become quite unsafe, and was a source of danger to the new bridge.

J. R. B. SERJEANT, CAPT., R.E.,
Comdg. 1st Company, Bengal Sappers and Miners.

REPORT ON THE CHITRAL BRIDGE
(*Plates* XXIV., XXV., XXVI.).

BY MAJOR F. J. AYLMER, V.C., R.E.

General.—On the first arrival of the Relief Force at Chitral in May, 1895, with a view to the possible future occupation of the country by a British force, the General Officer Commanding, and the Commanding Royal Engineer, selected a site for a suspension bridge over the Chitral river with a fort on the right bank to protect it. In order to prevent the fort being commanded, it became necessary to have the site of the suspension bridge where the banks were flat and the span very great.

Site.—The site chosen was about 1½ miles below the old Chitral Fort. *Plate* XXV. gives a section of the river at this point with an elevation of the bridge. The bed of the river up to 10 feet above the ordinary flood level consists of boulders, shingle and sand, and above that level of ordinary alluvial deposit. Every 30 or 40 years extraordinary floods occur. These are caused by an advancing side glacier blocking some main channel above Chitral. A lake is formed which finally carries away the side glacier, causing a sudden rush of water. To provide against such floods the roadway was built 15 feet above ordinary flood level, necessitating a span of 294 feet.

Material.—The large frames were entirely constructed of pine wood joined with spikes and wire. All the wood for frames, cribs and roadway had to be brought down from forests some 4 miles off and about 3,000 feet above the bridge site. As many of the timbers were very large, this entailed a great expenditure of labour. The only trees from which the larger timbers could be obtained were of soft wood, I believe the *pinus excelsa*, which made it necessary to employ heavy scantlings, especially for the frames. The only material available for the cables was telegraph wire with a tensile strength of 2,000 lbs ; of this some 20 miles have been used in the Chitral bridge.

Work on Bridge.—The 4th Company, Bengal Sappers and Miners, arrived at Chitral on the 21st of August, 1895. Previous to this Lieut. Freeland, R.E., had made certain preparations. The hole for the crib on the right bank had been excavated. Five large timbers 75 feet long and of minimum section of 12 inches and 12 inches had been brought down from the forests. Some 300 rough pine spars 15 to 22 feet long and a certain quantity of chesses had been collected at the site. A protecting pier on right bank had been constructed and two wire ropes with travellers, each carrying a single passenger, had been rigged up, and were in working order. From 22nd of August to 13th of September, when the bridge was finished, with the exception of small shore trestles, the average daily working parties were :—

4th Company, B. S. and M.	110	rank	and file
Native Infantry	15	,,	,,
Coolies on bridge and cutting wood	200		

The sappers and coolies worked generally from 6 a.m. to 3 p.m., and the infantry from 6.30 a.m. till 12 noon.

Description of Bridge Cribs.—The cribs were sunk from 5 to 6 feet in the boulders and shingle, and had a total height of 15 feet. Their length at top was 42 feet interior measurement, which allowed of the main props for compound frames being fixed at a good angle. The width of 10 feet at top was considered the minimum for stability. The different faces of the crib were at a slope of $\frac{6}{1}$. Eight unsquared timbers about 9 inches diameter were first set up at the required angles at the corners. The horizontal timbers of the cribwork were built up between and within these 9-inch corner props and fitted into each other at the corners. The 9-inch corner props were bound to each other by diagonal lashings of wire at every 3 feet of height. Large flat stones were carefully packed from the inside between the horizontal spars of the cribwork, and the whole interior space packed with large stones (*Plate* XXVI., *Figs.* 1, 2 and 3).

Frames.—On account of the great height of frames (51 feet), it was impossible to get single timbers strong enough to support the great crushing force produced by the cables, so compound legs, Λ shape, were constructed. Full details are given in *Plate* XXVI., *Figs.* 2 and 3. The main timbers were 50 feet long and over 12 inches by 12 inches in section. Each pair was fastened together by cross and diagonal bracing secured by 10-inch spikes. This double spar weighed about 2 tons and was raised by a derrick; when it was in position and well guyed it served as a derrick to raise the second double spar. These two double spars rested on carefully levelled footings at the bottoms of the cribs and were twelve feet from centre to centre. Each was fitted at top with a tenon of $1\frac{1}{2}$ inches round iron projecting 6 inches. The top cross piece of 12 inches by 9 feet was then placed on these, iron straps 5 feet 6 inches long, 3 inches wide and $\frac{1}{2}$ inch thick, for cables to pass over, were bolted to the frames, and the frame was then braced across and diagonally (*Fig.* 3, *Plate* XXVI.) by spars 6 inches by 6 inches. When the cribwork had been built up to about 14 feet, three props were added at either side. The whole frame was securely tied back to subsidiary anchorages by two cables of 14 wires each (28,000 lbs. tensile strength).

Cables.—Each cable consisted of 58 telegraph wires, and had a tensile strength of 116,000 lbs. Taking weight of roadway at 90 lbs. per foot run, and infantry crowded in single rank as 210 lbs. per foot run, total 300 lbs. per foot run, span 292 feet, dip $\frac{1}{10}$, this allowed of a factor of safety of 2. To prevent any possibility of accidents, however, only 12 laden mules or 50 men were allowed on the bridge at the same time. The total length of each cable was 600 feet, and they were constructed as described in the case of the Panjkora bridge or in my "Notes on Bridging" published in the *R.E. Professional Papers.*

Anchorages.—The anchorages consisted of round timbers 22 feet long, and with a minimum diameter of 18 inches. They were placed in trenches 6 feet deep and further strengthened by large stone piers above and in front (*Plate* XXV.).

Fixing of Cables.—One end of the cable was fixed to the anchorage by passing it round 3 times and then fastening the short end to the standing part by opening it up and lashing with numerous thin wire lashings. The long end was then passed over the near frame and pulled across to the other side of the river over the far frame, being finally secured to the far anchorage in the same way as it was to the near one. To prevent the heavy cable dipping into the water when being pulled across, it was supported at intervals by single blocks running on a 3-inch manilla cable, which was tightly stretched between the tops of the frames. The cables were fixed with a dip of a little less than $\frac{1}{12}$, to allow for stretching and lightening at anchorages.

Roadway.—The roadway was then built out in the ordinary way. The slings were 7 feet apart and each was of four wires giving a tensile strength of 8,000 lbs. They were attached to the cables simply by their top ends being tightly twisted round the cables three times and then round the slings themselves. The transoms were of 9-inch round timbers lying in the loops of the slings. The roadbearers were four in number, being 6-inch spars. They were placed breaking joint, many passing over as many as four or five transoms. The chesses were of rough split fir timber, 6 feet long, 15 inches wide and 2 inches thick. Long ribands and diagonal railings were added. To prevent sinking at the ends of the bridge from concentrated loads, inclined props 34 feet long were got into position, and the bridge was completed by the addition of wind stays from every alternate transom fastened to props up and down stream.

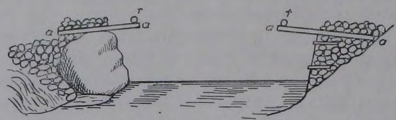
Time.—The 4th Company, Bengal S. and M., began work on the 22nd August. By the 4th September the cribwork and frames were finished. By the 6th September both cables were secured, and on the 10th the roadway was so far complete that 80 mules passed over safely. On 11th, 12th and 13th, railings, wind stays, end props, etc., etc., were added. The work was delayed slightly by the failure of the local authorities to deliver the big spars on the dates fixed.

CANTILEVER BRIDGES (*Plates* XXX.—XXXVI.).

1. Throughout Kashmir, Ladak and Chitral the most common form of bridge, and the only one made by the local people that is suitable for the passage of transport animals, is the Cantilever Bridge. As military engineering books take little or no notice of this extremely useful form of bridge, a few words on the subject may not be out of place.

2. *Construction.*—From the smallest to the largest span, which may be taken as 120 feet, the method of construction is practically identical. A site is chosen where a large rock or rocks rise out of the stream or a pier is constructed of dry stonework and wooden bindings. On the top of these are laid a number of stout beams *aa*, *a′a′*, *a″a″*, projecting over the stream, with the projecting end somewhat higher than the shore ends. The number of beams, their

length and amount of projection depend on the span. Stones are packed round the shore ends of these cantilevers, and they are then covered up with large bits of rock. Transoms *tt*, *tt*, are then placed near the projecting ends (*Figs.* 1 & 2). If after this the span



Elevation.
Fig. 1.

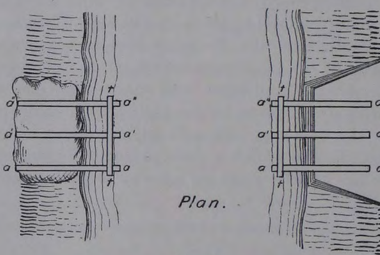


Fig. 2.

between the transoms is sufficiently small, central roadbearers *rr* are put into position, the number and size depending on the span. If the span is small, one or two cantilevers are necessary (*Figs.* 3 & 4).

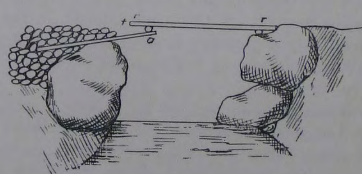


Fig. 3.

Supposing in *Fig.* 4 that the central span is too large for available timbers, then a second row of cantilevers *bb* is placed on the first

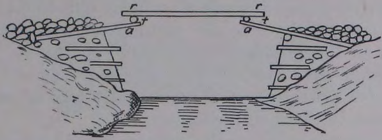


Fig. 4.

row *aa*, two more transoms *t't'* are placed near the projecting ends and the roadbearers *rr* are placed in position (*Fig.* 5). There are

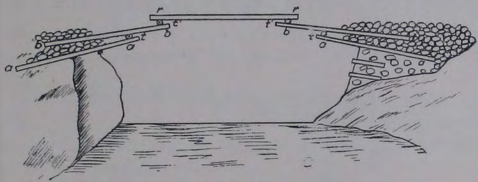


Fig. 5.

generally more cantilevers in the bottom row than in the row above, and so on.

Fig. 6 gives the Chitral bridge, 120 feet span. In this the

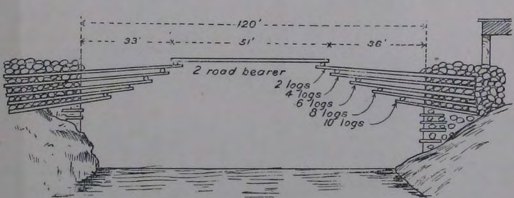


Fig. 6.

timbers are very large, being from 15 inches to 18 inches in diameter. There are ten logs in each of the bottom row of cantilevers, eight in the next, six in the next, four in the next, and two n the top row. There are only two central roadbearers.

The only chesses used as a rule are roughly split bits of pine wood. These are fastened down to the central roadbearers and the top layers of cantilevers by thin ribands secured by withies. The roadway is about 4 feet wide, and there are seldom any railings. The above is a fair description of the cantilever bridge in its primitive state, in which it is generally seen.

3. Many improvements can be made provided time and material are available.

(1). The step from top row of cantilevers to top of central roadbearers can be avoided

(*a*). By lashing the top transom *t* underneath the ends of the top row of cantilevers instead of placing it on the top; wire is best for this (*Fig.* 7).

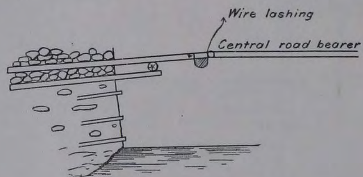


Fig. 7.

(*b*). An extra row of roadbears may be added above the top row of cantilevers (*Fig.* 8).

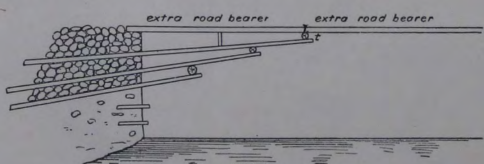


Fig. 8.

2. The counter-weighting of the cantilevers may be improved by covering the shore ends of each row with thin bits of wood or rough-

chesses before covering them up with stones, also by fastening the top layers to the bottom ones by wire (*Fig.* 9).

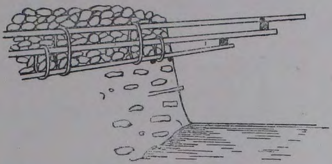


Fig. 9.

3. A better class of chesses may be used and properly fastened down to the roadbearers with wire nails and ribands. The best chesses can be made out of the doors of the houses in the neighbourhood.

4. Railings should be added, and, to prevent beasts getting frightened, these should be made into regular screens by aid of boughs of trees. The railings should be given an outward splay so as not to catch the loads (*Fig.* 10).

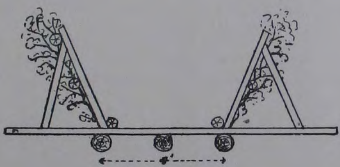


Fig. 10.

(5). Earth and grass should be spread over the roadway to prevent animals being frightened at the noise.

(6). In the case of a long bridge, a few wire ties are a great improvement, as they stiffen the bridge greatly (*Fig.* 11).

This kind of bridge has the following advantages :—

(1). The construction needs no skilled labour of any kind.

(2). No material except wood and stone is absolutely necessary, though, as has been pointed out, a better bridge can be made if some wire be available.

(3). Very few tools, and those of the simplest kind, such as felling axes, are required.

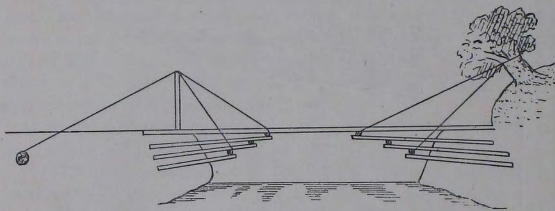


Fig. 11.

(4). This bridge can be made when, on account of the shortness of the timber, no other except a suspension bridge is possible.

(5). When timber is close at hand, and large working parties are available, it can be very rapidly constructed.

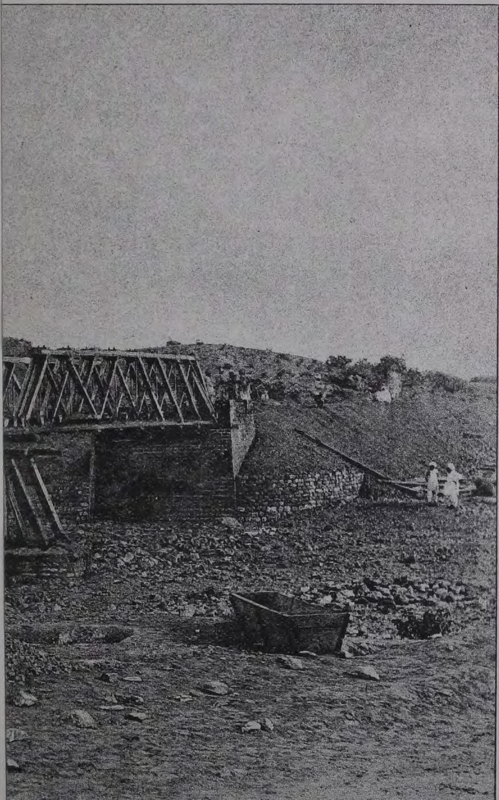
(6). When finished it lasts a very long time without requiring any repairs except the renewal of chesses.

5. These bridges, though strong, are generally somewhat jumpy, especially when of great span, but if railed and screened with bushes, the shiest animal will go freely over them. When over 50 or 60 feet in span, traffic must be carefully regulated.

6. Numerous bridges of this type were made at various places on the road, especially between Dir and Chitral.

DGE

PLATE I.



PAPER VII.

NOTES ON INDENTS FOR PIPES AND OTHER STORES FOR WATERWORKS.

By Major D. C. Courtney, late R.E.

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Introduction.

These notes are intended to bring to the notice of Indenting Officers the specifications and drawings used by the Store Department of the India Office in contracts for stores for waterworks, and also to draw attention to the particulars which should be furnished in indents for these stores.

It is hoped that the labour expended in India on the preparation of special specifications and drawings may thus be reduced.

The Appendix contains tables of the weights of cast-iron pipes, and of constants for approximate hydraulic calculations of a simple description.

Cast-Iron Pipes.

Straight Lengths of Uniform Bore.

1. The particulars required are :—

(*a*). Description of joint, viz. :—

Plain spigot and socket ... Drawing 2781 (page 218).

Turned and bored spigot and socket ... ... ,, 2782 (page 219).

Flanged ... ... Table of Flanges (page 220).

(*b*). Bore.

(*c*). Thickness.

(*d*). Length.

Joints.—Pipes with plain joints accommodate themselves to settlements and to slight variations of direction. If the joints are caulked with gasket and lead,* contraction can take place without deformation of the lead; considerable labour and care are, however, required to ensure tight joints.

Pipes with turned and bored joints can be more easily and quickly laid than those with plain joints, but the joint is rigid and allows very little deviation from a straight line. If the joints are caulked with lead,* contraction cannot take place without deformation of the lead, or, if the lead be omitted, without risk of leaks; if expansion take place, the weaker sockets are likely to be split by wedge action. To allow of expansion and contraction, a plain socket is sometimes used for every tenth joint; when this arrangement is adopted the pipes should be demanded as follows, viz.:—

80	per cent.	with turned and bored joints.
10	,,	,, turned spigots and plain sockets.
10	,,	,, plain spigots and bored sockets.

In reference to connections between pipes with plain joints and those with turned and bored joints, it should be noted that a turned spigot will enter a plain socket, but that a plain spigot will not enter a bored socket unless the greater part of the bead is first chipped off.

The spigot ends of pipes exceeding 10 inches in bore are sometimes "hooped" for greater security in transit; the hoops are of wrought iron about $1\frac{1}{2} \times \frac{5}{16}$ inch, and are shrunk on, so that in the case of plain spigots the bead must be omitted when hooping is required. The sockets of large pipes are sometimes hooped in the same manner. When hooping is required, the following particulars should be given in the indent:—

(i.). Bores of pipes to be hooped.

(ii.). Whether the spigots, or both sockets and spigots, are to be hooped.

Flanged joints allow of no deviation from a straight line; they are generally used for vertical pipes and in special positions, such as connections for valves, pumps, meters, and other fittings. Flanges

* In the case of pipes which have been exposed in open trenches to a tropical sun, some contraction must take place when the trenches are filled in. A reduction in temperature of 60° F., *e.g.* from 140° to 80°, would cause a contraction of 0·44 inch per 100 feet.

of pipes required for connection to existing work already drilled for bolts should be demanded "blind," to prevent the risk of a misfit. When all flanges are ordered to be drilled, it is advisable to order a few short lengths (about 9 inches) with one flange only drilled; these can be fitted between any two flanges in which the positions of the bolt holes do not correspond, and the necessary holes marked and drilled in the "blind" flange; these short lengths have the advantage of being easily handled. The flanges of pipes intended to be fixed in a vertical position should be faced all over, and, if the height be considerable, "feathers" or brackets should be cast in the spaces between the bolt-holes.

Bore.—For bores of less than 2 inches, wrought-iron pipes are generally used in preference to cast-iron pipes; the latter are less liable to corrosion, but are very easily fractured. Taking first cost, freight, risk of breakage in transit, and jointing into account, it would probably be more economical not to use cast-iron pipes of less than $2\frac{1}{2}$ inches bore.

Thickness.—In ordinary cases, *i.e.*, head of water not exceeding 300 feet and bore of pipe not exceeding 20 inches, the thicknesses of cast-iron pipes are governed by the risk of breakage in transit and in handling, and not by the stress due to hydrostatic pressure. The least thicknesses recommended are as follows, viz. :—

Bores of Pipes, inches ...	Up to 4	$4\frac{1}{2}$ to 6	$6\frac{1}{2}$ to 8	$8\frac{1}{2}$ to 9	$9\frac{1}{2}$ to 12	13 to 15	16 to 18	19 to 20
Thickness, inches ...	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{7}{8}$

Some of the numerous formulæ used for calculating the thicknesses of cast-iron pipes are given in the Appendix.

Length.—Pipes of less than 3 inches bore are supplied in lengths of 6 feet, those from to 3 to 20 inches bore in lengths of 9 feet, and those above 20 inches bore in lengths of 12 feet; these lengths are exclusive of sockets, but inclusive of flanges. Pipes of 12 inches bore and upwards can, however, be supplied in lengths of 12 feet. The price per ton would probably be slightly higher than for 9 feet lengths, but the total weight for any given distance would be reduced, and the saving of 25 per cent. in the number of joints to be made would effect considerable economy in the cost of laying the pipes. The number of lengths required should always be stated in indents, as well as the estimated weight; about 4 per cent. should be allowed in addition to actual requirements, to cover breakage in transit.

Bends and other Ordinary Forms.

2. These include :—

Bends.	Flanged spigots.
Diminishing pieces.	,, sockets.
Tees.	Double sockets.
Crosses.	Pipes with two spigot ends.
Branch pipes.	Collars or thimbles.

The particulars required are as follows :—

Bends.—Bore, angle contained between extreme radii and description of joints, *e.g.*, "plain socket and spigot," "bored socket and flange"; also, if a special radius be required, the radius to axis of bore; if possible, the radius should not be less than than three times the bore. The sockets and spigots of bends are cast straight; the straight portion of the spigot is 6 inches long (*Fig.* 1, *Plate* I.). In the case of flanged bends, it should be stated whether the bolt holes are to be drilled or not; it is advisable to leave at least one flange "blind," so that the bolt-holes may be drilled to suit any required "cant." Bends intended to carry a vertical pipe should be demanded as "duckfoot bends" (*Figs.* 3 and 4, *Plate* I.), so that the foot may be bedded on a horizontal foundation. In order to reduce the frictional resistance of bends, their bores are sometimes made larger than those of the straight pipes in connection with them; in such cases two suitable straight diminishing pipes should be demanded for each bend.

Diminishing Pipes.—Bore, and description of joint, at each end, *e.g.*, "6-inch plain socket, 4-inch flanged." The spigots and sockets of diminishing pipes are cast straight (*Fig.* 7, *Plate* I.). A diverging pipe, for reducing the velocity of discharge from the end of a pipe, is shown in *Fig.* 15, *Plate* I. The angle of divergence should be 5° 6′, and the length of the diverging portion not less than $9d$ nor more than $20d$, where d = bore of smaller end; when the length of the diverging portion does not exceed $15d$ a bell-mouth (*Fig.* 13, *Plate* I.) may be added with advantage at the larger end. The same particulars are required as for a diminishing pipe. Bell-mouths, if required, should be demanded separately, with a note that they are to fit the diverging pipes.

*Tees.**—Bores and descriptions of joints of main and branch, *e.g.*, "6-inch main, plain spigot and socket; 4-inch branch, flanged"; when flanged branches are ordered the flanges are left blind unless otherwise specified in the indent.

*Crosses.**—Description of joints, and diagram showing bores, thus:—

Similar particulars, with the addition of the angles between the branches, are sufficient for a three-way pipe.

*Branch Pipes.**—As for tees, with the addition of the *acute* angle between the axes of main and branch. When the joints at the ends of the main differ, a diagram should be added to show from which end the acute angle is measured (*Figs.* 8 and 9, *Plate* I.).

Flanged Spigots and Flanged Sockets.—Bore and description of spigot or socket.

Double Sockets.†—Bore of pipe and description of socket.

Collars.†—Bore of pipe.

Pipes with Spigots at both ends.—Bore, description of spigots, and length of pipe.

The thicknesses of the pipes should be added to the above particulars if not previously stated in the demand for straight pipes.

If the same description of joint is to be used for all the pipes and specials included in an indent, it need only be stated in the demand for straight pipes, and a general note added that the specials are to suit the straight pipes.

Special Castings.

3. The particulars should be given on diagrams with dimensions. If several castings are to be fitted together in the work, it is well to

* The branches of these castings should always have sockets or flanges, and not spigots; the latter are very likely to be broken in transit even if short, and short spigots do not allow sufficient space for the use of caulking tools. When a spigot is necessary for jointing, it can be provided by ordering (i.) a pipe with two spigot ends, if the branch have a socket; or (ii.) a flanged spigot, if the branch be flanged.

† A double socket is used for joining two spigot ends, and has a short length in the centre of the same bore as the pipes it joins. A collar is used for joining two cut ends, and can be slipped over the plain portions of a pipe (*Figs.* 10 and 11, *Plate* I.).

show them together in the diagrams, so that the fitting may be tested. Socket and spigot joints should be described on the diagrams as "Plain" or "T and B," and dimensions which may be varied slightly should be distinguished from those which are required to be exact by stating limits in the case of the former, thus: "1 to 2 feet."

Sluice Valves.

4. The particulars to be furnished for sluice valves are the sizes (bores), the depth from surface of ground to axis of valve, and the number of tee keys required to fit each size of valve.

Sluice valves with flanged ends, as described in the specification (page 221), are recommended for use with spigot and socket pipes as well as with flanged pipes, because they can be removed for repairs without breaking a pipe; the necessary flanged spigots and flanged sockets (one of each for each valve) should be demanded as a separate item, the description of joint—plain or turned and bored—being also specified. Surface boxes, for the protection of the spindles, should likewise be demanded separately.

When sluice valves are required in connection with hydrants they should be demanded as parts of the hydrants, and not separately, otherwise a double supply is likely to be made. Valves intended for use with wrought-iron pipes should be distinguished as "screwed for wrought-iron pipes" or "flanged for wrought-iron pipes."

Self-acting Air Valves.

5. There are three descriptions:—

(i.). Single, with small orifice for discharge of air under pressure.

(ii.). Single, with large orifice for discharge of air when filling pipes.

(iii.). Double, with one orifice as (i.) and one as (ii.).

Valves of description (i.) can be supplied either with screwed shanks (male) or flanged; valves of descriptions (ii.) and (iii.) are flanged.

The following particulars should be furnished, viz.:—

For description (i.). Pressure (static) of water at point where the valve is to be fixed, and description of shank, screwed or flanged. If the valve is to be fixed on a wrought-iron pipe it should be demanded "with tee to fit wrought-iron pipe," and the bore of the latter stated.

For description (ii.). Bore of inlet, generally 2 to 4 inches.

For description (iii.). Pressure as for (i.) and bore of inlet.

A tee with flanged branch should be demanded for the connection of each flanged air valve. If no stop-cock or sluice valve is fixed between the main and an air valve, the latter cannot be repaired whilst the main is under pressure; hence, if the maintenance of a constant supply be important, air valves should be demanded "with stop valve," or, if the inlet exceed 2 inches bore (descriptions (ii.) and (iii.) only), "with sluice valve and two flanged bends of 90°"; the bends would allow the sluice valve to be fixed between them with the spindle vertical.

A surface box should be demanded for each air valve.

The pressure is required in the cases of valves (i.) and (iii.), to enable the manufacturer to determine the diameters of the balls.

Reflux Valves.

6. Reflux valves are flanged; each requires a flanged spigot and a flanged socket when fixed in a line of spigot and socket pipes. The particulars required are the bore, and the height of the column of water to be sustained. The faces, hinge bolt and bushes should be of gun-metal.

Hydrants.

7. Hydrants may conveniently be divided into two classes, viz.: pillar hydrants and pit hydrants. Pillar hydrants are preferable when there is space for their erection, provided there is no risk of injury from frost. In the cheaper forms of pillar hydrant the pillar is a branch of the supply pipe, with an outlet—usually near the top—screwed to suit the hose coupling, and a valve to control the supply; the valve is generally a sluice valve fixed underground (*Fig.* 16, *Plate* II.), and worked by a tee key; in some patterns, however, the valve is a spindle valve connected with the outlet and worked by a fixed hand-wheel (*Fig.* 17, *Plate* II.), or by a loose key or handle fitting the square of the spindle. In the more expensive forms the pillar is a casing surrounding the pipe (*Figs.* 18 and 19, *Plate* II.); the space between the casing and the pipe is sometimes utilized for the working parts of self-closing taps (Kennedy's pattern) for domestic supply; the wrought-iron pipe supplying the taps is connected with the body of the sluice valve behind the sluice, so that the taps may be used without opening the sluice valve, and is commanded by a stop-cock (*Fig.* 19, *Plate* II.). When several taps are required, the hydrant outlet is often placed near the base of

the pillar, so as to leave space above it for the working parts of the taps. The outlets of pillar hydrants are protected with chained caps screwed to fit them.

The principal forms of pit hydrants are spindle hydrants (*Fig.* 20, *Plate* II.) and sluice-valve hydrants (*Fig.* 21, *Plate* II.). In both these forms the valve is worked with a tee key or with a fixed hand-wheel, and the outlet (unless there be more than one) is vertical. As the direct connection of delivery hose to a vertical outlet would cause a sharp bend in the hose, a portable stand-pipe (usually of brass or copper), with a swivel head for the hose, should always be provided for use with pit hydrants having vertical outlets. When there are two outlets (*Figs.* 22 and 23, *Plate* II.), they are generally inclined to the vertical, and hose may be connected directly to them. Spindle hydrants are made with horizontal flanges for connection to the flanges of bends or of vertical branches from a main; sluice-valve hydrants have vertical flanges for connection to sluice valves; they give a clearer and more direct water-way than spindle hydrants, and are, therefore, preferable, though more expensive. The outlets of pit hydrants are protected with loosely-fitting chained caps.

The following nomenclature is recommended for adoption :—

(i.). Pillar hydrant, uncased, with sluice valve.

(ii.). ,, ,, ,, ,, spindle valve at top.

(iii.). ,, ,, cased, with sluice valve.

(iv.). ,, ,, ,, ,, spindle valve at top.

(v.). Combined pillar hydrant and fountain, cased, with sluice valve.

(vi.). Pit hydrant with spindle valve.

(vii.). ,, ,, ,, sluice valve.

The particulars which should be furnished for a hydrant are as follows :—

(*a*). General description, using nomenclature suggested above.

(*b*). Bore (generally $2\frac{1}{2}$ inches) and number (1 or 2) of outlets.

(*c*). Size (bore) of sluice valve, if the hydrant require one; a 3-inch valve is recommended for one $2\frac{1}{2}$-inch outlet, and a 4-inch valve for two $2\frac{1}{2}$-inch outlets.

(*d*). If tee keys, or, in the case of (ii.) and (iv.), loose keys or handles be required, state the number required to fit each size of valve.

(*e*). If fixed hand-wheels be required for (ii.), (iv.), (vi.) or (vii.), add "with hand-wheel" to general description.

(*f*). Bore (usually $\frac{3}{4}$-inch) and number of self-closing taps for (v.).

The necessary surface boxes, the flanged spigots or flanged sockets required for the connections between the supply pipe and the valve or flanged bend ((i.) to (v.) and (vii.)), and the tees with flanged branches for (vi.) should be demanded as separate items. In the case of the surface boxes, reference should be given to the hydrants for which they are demanded, so that the sizes may suit requirements. If the bore of the supply pipe be greater than the bore of the valve or flanged bend, suitable diminishing pipes should be demanded instead of flanged spigots or flanged sockets.

The bore of the supply pipe should never be less than 3 inches for a single $2\frac{1}{2}$-inch hydrant, or 4 inches for a hydrant with two $2\frac{1}{2}$-inch outlets, but in either case it would be better to use larger pipes if possible, so as to reduce the velocity and loss of head from friction; thus, if a 6-inch main were available, it would be better to make the branch 6 inches and provide a flanged reducing piece for connection to the valve or bend than to choke the branch to the bore of the valve or bend. For the extinction of fire a hydrant should deliver not less than 150 gallons a minute to a fire engine, or 80 gallons a minute through 150 feet of $2\frac{1}{2}$-inch hose. The heads which would be expended in friction to produce these discharges through an imaginary series of pipes are stated below; the pipes are supposed to be "clean":—

Bore of Pipe, inches...		10	8	6	4	3	$2\frac{1}{2}$ hose.	Total Frictional Head.
Length of Pipe, feet...		1,000	500	500	500	500	150	
Frictional head in feet for	Galls. 150	0·22	0·35	1·51	12·30	55·30	—	69·68
	80	0·06	0·10	0·43	3·50	15·76	12·30	32·15

The heads required to produce the velocities of discharge would be 2·15 feet for the 150 gallons, and 43·32 feet for the 80 gallons if the latter were discharged through a $\frac{7}{8}$-inch nozzle; the total heads would thus be about 72 and 75 feet respectively. The large proportion of head consumed in the 3-inch pipe, particularly in the case of the 150 gallons, is apparent. Generally, the maximum consumption of water at a given point in a given time will be found to be due to fire extinction; the minimum bore of the smaller mains at any rate will thus depend on the supply required for the hydrants, and can seldom be less than 4 inches; in most cases, however, it would be better to make 6 inches the minimum bore. Whenever possible, fire mains should be supplied from both ends, *i.e.*, there should be no "dead" ends.

The outlets of all hydrants supplied by the Store Department are screwed (male) to the Old Metropolitan V thread—five threads to an inch. The external diameter over the threads is as follows, viz.:—

$3\frac{1}{4}$ inches for outlets from $1\frac{3}{4}$ to $2\frac{1}{2}$ inches bore.
$3\frac{5}{8}$,, ,, of $2\frac{3}{4}$ inches bore.
4 ,, ,, of 3 ,, ,,

Delivery Hose, Branch Pipes, and Nozzles.

8. Canvas hose inlined with indiarubber is recommended in preference to leather hose or plain canvas hose, as it requires less care to maintain it in good order. The bore or waterway of the couplings is always $\frac{1}{4}$ inch less than the bore of the hose, as the latter must correspond with the *external* diameter of the shanks of the couplings; thus the waterway of the couplings of $2\frac{1}{2}$-inch hose (the ordinary size) is $2\frac{1}{4}$ inches. The couplings are screwed, as described above, for hydrants; lengths of hose from 2 to $2\frac{3}{4}$ inches bore can, therefore, be coupled up together if necessary. When hose of smaller bore than 2 inches is demanded, the couplings are screwed as shown below, unless otherwise specified in the indent; it is most desirable, however, that there should be no departure from the standard sizes.

Bore of Hose.	Bore or Waterway of Coupling.	External Diameter over Tnreads.	No. of Threads per inch.
Inches.	Inches.	Inches.	Inches.
$1\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{1}{16}$	7
$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{25}{32}$	8
$1\frac{1}{4}$	1	$1\frac{5}{8}$	8
1	$\frac{3}{4}$	$1\frac{3}{8}$	8

The particulars required for delivery hose are description, *e.g.*, leather, canvas inlined with rubber, etc., bore and length, also whether with or without couplings.

The larger ends of branch pipes are screwed (female) to fit the couplings of the hose for which they are required; the smaller ends are screwed (male) to fit the nozzle or nozzles supplied with them. When branch pipes are demanded without hose, the bore of the hose with which they are to be used should be stated; and if the couplings are not screwed to one of the standards mentioned above, full particulars of the screws should be added, including the external diameter of the male thread and the number of threads per inch; in such cases, however, a sample pair of couplings should, if possible, be sent home. The bores of the nozzles required should always be specified; several nozzles of different bores can be supplied, if desired, with one branch pipe, so that the nozzle best suited for any particular purpose may be used at will.

Water Meters.

9. The following particulars should be furnished in demands for water meters:—

(1). General description *e.g.*, "Siemens'," "Kennedy's," "Tylor's," etc.

(2). Maximum quantity of water to be passed in gallons per hour.

(3). "Effective" head in feet at the point where the meter is to be fixed, *i.e.*, the head which would be shown, *whilst the maximum quantity of water was passing*, by a hydraulic gauge attached to the inlet of the meter.

(4). Bore and description (cast iron, wrought iron, or lead) of the pipe to which the meter is to be connected.

(5). Whether the meter is to be fixed above or under the ground.

Each meter requires a dirt box, a surface box (if fixed underground), and two sluice valves, with suitable flanged connecting pieces between the valves and the main.

If only one meter is provided, a spare piece of flanged pipe should be demanded to take the place of the meter when the latter is removed for repairs, or else a by-pass with sluice valve should be added (*Fig.* 24, *Plate* III.). Very often, however, two or more smaller meters are used instead of one large meter, so that one can be taken out for repairs without stopping the supply through the others. When there are more meters than one, two flanged "breeches" pipes should be demanded for the connections between the valves and the main (*Fig.* 24A, *Plate* III.); a sketch of the proposed arrangement should also be furnished.

Pumps.

10. When a pump is to be supplied in strict accordance with a catalogue description, the only particulars required are a reference to the catalogue and any details as to size, etc., necessary to ensure correct supply.

When a pump to perform specified work is to be obtained by competitive tenders, the following particulars should be furnished:—

(1). General description, *e.g.*, "rotary," "direct acting," "centrifugal," etc.

(2). Power to be employed for working, *e.g.*, "hand," "bullock-gear," "steam," etc.

(3). Quantity of water to be pumped in gallons per minute.

(4). Vertical distance in feet from lowest water level in well, or other source of supply, to—

(*a*). Point of discharge of delivery pipe.

(*b*). Top of barrel or upper side of pump cylinder, or to the floor of the pump-house.

(*c*). Highest water level in well.

(5). The total lengths and the bores of the delivery and suction pipes respectively. A sketch, with dimensions showing the axis of the suction pipe in plan and section, is generally advisable.

(6). The total number of degrees in the bends in the delivery and suction pipes respectively; *e.g.*, if there were 10 bends of 15° and six of 20° in a delivery pipe, the total number of degrees would be 270.

(7). If the pump is to be worked by steam, the number of hours of continuous work required.

(8). If the steam is to be supplied from an existing boiler:—

(*a*). The dimensions and description of the boiler.

(*b*). The number of cubic feet of water evaporated per hour.

(*c*). The working steam pressure which can be maintained.

(9). If the pump is to be driven from existing shafting:—

(*a*). The diameter and speed (revolutions per minute) of the shafting.

(*b*). The diameter of the largest pulley which could be fixed to the shafting for driving the pump.

(*c*). The horse-power available for the service of the pump.

(10). The average height of the barometer at the station where the pump is to be fixed, or the height of the station above sea level.

(11). The usual temperature (in degrees F.) of the water.

In addition to the above, sketches should be furnished, when necessary, showing in plan and section the positions of the pump, well, and boiler or other driving power.

Suction Pipes.—The suction pipe should always be as short as possible, and the head of water required to balance the vertical lift to the pump and to overcome the frictional and other resistances in the whole length of this pipe should not exceed about $\frac{4}{5}$ of the head* corresponding to the average barometrical reading.

A foot valve and strainer are generally fixed at the end of the suction pipe ; the total area of the holes in the strainer should not be less than twice the area of the bore of the pipe. When it is possible to guard the approach to the foot valve with screens suitable for keeping out flotsam and fish, a bell-mouth may with advantage be fixed immediately below the foot valve instead of a strainer. There should be a clear space round and below the strainer or bell-mouth, so that the water may approach from all directions without eddies. When the suction pipe is necessarily long or the suction lift high (*i.e.*, more than from 15 feet for a 3-inch pump to 18 feet for a 6-inch or larger pump), an air vessel should be fixed on it close to the pump, so as to reduce the concussion between the rising column of water and the suction valve of the pump.

Delivery Pipes.—A reflux valve should be fixed between the pump and the delivery pipe, and, if the pump have to work against a high pressure, there should be a relief valve between the reflux valve and the pump, to prevent accidents from over-pressure.

Sluice valves should not be fixed on a delivery pipe unless a relief valve has been provided. A diagram showing the relative positions of the relief and other valves on a delivery pipe is given in *Fig.* 25, *Plate* III.

Velocity in Suction and Delivery Pipes.—In order to reduce frictional resistance, the velocity of water in suction and delivery pipes (those of centrifugal pumps excepted) should not exceed from 2 feet a second for small pipes (say 6 inches and under) to 4 feet a second for large pipes. If G represent the required discharge in gallons per *minute*, the bores of clean pipes for velocities of 2 and 4 feet a second would be, in inches, about $\cdot 5\sqrt{G}$ and $\cdot 35\sqrt{G}$ respectively, omitting, however, any allowance for incrustation. When circumstances render

* The specific gravity of mercury is 13·6 ; hence $\frac{4}{5}$ of the head of water in feet corresponding to B inches of mercury $= \frac{4}{5} \times 13{\cdot}6 \times \frac{B}{12} = {\cdot}90B$.

a long suction pipe unavoidable, it may be necessary to increase the bore to a size larger than that given by $\cdot 5 \sqrt{G}$ or $\cdot 35 \sqrt{G}$. When the bore of the suction pipe is larger than that for which a pump is designed, the connection to the pump flange can be effected by a flanged reducing piece, so as not to interfere with the standard pattern of the pump.

In the case of centrifugal pumps—which are chiefly used for large quantities of water and low lifts—the velocity of the suction and delivery pipes varies from about 6 to 9 feet a second.

Tanks.

11. Large storage tanks for erection on water towers are generally constructed of flanged cast-iron plates 4 feet $\times$ 4 feet, not less than $\frac{5}{8}$ inch thick, prepared for bolting together. The horizontal and vertical angles are formed of quadrant pieces 4 feet long $\times$ 9 inches radius, and the bottom corners of quarter-sphere pieces. The flanges are 3 inches deep, and project into the inside of the tank; they have planed facing strips and holes for $\frac{5}{8}$-inch bolts at 6-inch centres. The plates, etc., are first put together with bolts and nuts, and the spaces between the flanges subsequently caulked with cast-iron cement*; diagonal stays of wrought iron, from the flanges of the sides to the flanges of the bottom, are fixed at intervals of 4 feet; each should have a coupling screw (right and left-hand) in the centre.

These plates, etc., are suitable for rectangular tanks $4\frac{3}{4}$ or $8\frac{3}{4}$ feet deep, but for the latter depth the plates forming the bottom of the tank should be $\frac{7}{8}$ inch thick; each side of the rectangle must measure $1\frac{1}{2}$ feet + a multiple of 4 feet.

The top of the overflow pipe should be 3 inches below the top of the tank, and a waste outlet with sluice valve should be provided, so that the tank may be completely emptied for cleansing without disturbing the overflow pipe.

Sluice valves should be fixed on the rising and falling mains just below the bottom of the tank, and a by-pass pipe with sluice valve between the two mains, so that when the tank is emptied for cleansing a supply may be maintained through the by-pass. The bell-mouth of the falling main should project 2 or 3 inches above the bottom of

* Salammoniac powdered ...	9 lbs.	made into a paste with water.
Flour of sulphur	1 lb.	
Cast-iron borings	200 lbs.	

the tank, to prevent sediment being swept into the pipe when the water is low.

The bottoms of cast-iron tanks are frequently covered with cement concrete to the level of the tops of the flanges, so as to give a smooth surface for periodical cleansing.

The general arrangement of pipes, etc., is shown in *Fig.* 26, *Plate* IV. A manhole $2\frac{1}{2}$ feet × $2\frac{1}{2}$ feet, for access to the tank, can be provided as shown in *Fig.* 27, *Plate* IV.; it requires special mitred quadrant pieces and plates 4 feet × $2\frac{1}{2}$ feet, with the flanges of the 4 feet sides set at an angle of 135° with the face of the plate.

The depth of the joists or girders supporting a tank should not be less than $\frac{1}{12}$ of the span; they may conveniently be placed at central intervals of 4 feet; the loads per foot run of joists for tanks $4\frac{3}{4}$ and $8\frac{3}{4}$ feet deep would be about $12\frac{1}{2}$ cwt. and 22 cwt. respectively; these loads allow for the tank being brimful, owing to a choked overflow, and also for 3 inches of concrete over the bottom of the tank.

If girders are used the flanges should, if possible, be formed of angle steel without a plate; if a plate be necessary, all the rivet-heads on the upper side of the top flange should be specified to be countersunk, so that the tank plates may bear on the whole surface of the girder flange, and not merely on the tops of the rivet-heads.

The particulars required for a cast-iron tank are as follows :—

(i.). Dimensions.

(ii.). Bores of pipes to be connected to the tank, viz., rising main, falling main, overflow and waste outlet, together with a sketch showing in plan the positions of these pipes; care should be taken that their flanged connections to the tank are clear of the joints between the plates and of the flanges of the supporting joists or girders.

(iii.). If a manhole be required for access to the tank, its position in plan should be shown on the sketch.

The weights of the principal components of cast-iron tanks are as follows, viz. :—

Plates $\frac{5}{8}$ inch thick	462 lbs. each.
„ $\frac{7}{8}$ „ „	612 „ „
Quadrant pieces	184 „ „
Quarter-sphere pieces	37 „ „
Bolts and nuts, two per foot run of joints and 10 per cent. spare are required...	90 „ per gross.

Sufficient materials for making cast-iron cement are supplied with each tank unless otherwise specified.

Wrought-iron Tanks.—Wrought-iron or steel tanks are less durable than those of cast iron, and, on account of the riveting, require more skilled labour for erection; they are, however, lighter than cast-iron tanks of the same capacities, and the plates, etc., are less liable to breakage in transit.

The plates, angles, tees, etc., can be supplied to suit any design, and the whole can be drilled for rivets, and marked for putting together; all the materials, except the rivets, can be galvanized, if desired.

The thicknesses of the plates, scantlings of the angles, etc., will depend on the design adopted, and on the spacing of the supporting joists, but the following are recommended as the least that should be used for a large tank :—

Plates	$\frac{5}{16}$ inch thick.
Angles...	$2 \times 2 \times \frac{1}{4}$.
Tees	$4 \times 2\frac{1}{2} \times \frac{5}{16}$.
Rivets	$\frac{5}{8}$ inch at $1\frac{5}{8}$-inch pitch.

Portions of a wrought-iron tank are shown in *Figs.* 29 to 32, *Plate* IV.

All tanks should be covered or roofed, and kept quite dark, to check the growth of vegetation.

Apparatus for Testing Pipes after Jointing.

12. Lines of pipes should, if possible, be tested by hydrostatic pressure after they have been laid and jointed, before the trenches are filled in, otherwise defective work is liable to escape observation, and cause leaks.

The apparatus required consists of :—

(i.) A portable pressure pump fitted with a gauge and a short length of delivery hose with suitable couplings.

(ii.) A pair of cast-iron flanges faced with leather (one for spigot ends, one for socket ends) for each bore of pipe to be tested, with wrought-iron clips and swing bolts. Each flange is fitted with a gun-metal nipple (screwed to the 1-inch gas thread) to take the hose coupling, and has a hole drilled and tapped to take the shank of an air cock.

(iii.) An air cock.

The flanges and the method of connecting them to a spigot or socket end are shown generally in *Figs.* 33 to 36, *Plate* V. For testing wrought-iron pipes the connection can be made with a few ordinary fittings, as shown in *Fig.* 37, *Plate* V.

The particulars required for testing apparatus are :—

Maximum testing pressure—200lbs. per square inch is generally sufficient.

Bores and thicknesses of cast-iron pipes to be tested.

Bores of wrought-iron pipes. Unless otherwise specified, a set of wrought-iron fittings, as shown in *Fig.* 37, *Plate* V., is supplied for each bore of wrought-iron pipe to be tested.

Wrought-iron Pipes.

13. The standard sizes (*i.e.*, nominal bores) of wrought-iron tubes for gas, water, and steam are as follows, viz. :—$\frac{1}{8}$ to $\frac{1}{2}$ inch, rising by $\frac{1}{8}$ inch, $\frac{3}{4}$ to 3 inches rising by $\frac{1}{4}$ inch, $3\frac{1}{2}$ and 4 inches. Tubes of less than $\frac{1}{2}$-inch bore are seldom required for water.

All makers publish the same trade list, with items numbered as follows :—

1. Tubes from 2 to 14 feet.
2. Tubes from 12 to $23\frac{1}{2}$ inches.
3. Tubes from 3 to $11\frac{1}{2}$ inches.
4. Long screws, 12 to $23\frac{1}{2}$ inches.
5. Long screws, 3 to $11\frac{1}{2}$ inches.
6. Bends, 90°.

7 to 9. Springs, various elevations, *i.e.*, bends of less than 90°.

10. Socket unions.
11. Pipe unions.
12. Elbows, equal or diminished.
13. Tees, } equal or diminished
14. Crosses, }
15. Sockets, plain.
16. Sockets, diminished.
17. Flanges.
18. Caps.
19. Plugs.
20. Back nuts.
21. Nipples.
22. Union bends.
23. Round elbows.

The ends of items 1 to 9, 11, 19, 21 and 22 are screwed male; those of items 10, 12 to 18, 20 and 23 are screwed female. A plain socket is provided with each tube or fitting supplied under items 1 to 3, and 6 to 9, and a special long socket and back nut with each long screw. Round elbows (item 23) are better than square elbows (item 12). Long screws, socket unions and pipe unions are useful in closing up work commenced from both ends; a long screw is used for closing between a socket and a pipe end, a socket union for closing between two pipe ends, and a pipe union for closing between two socket ends.

The following particulars should be furnished in indents for wrought-iron pipes:—

(*a*). Nominal bore.

(*b*). Purpose for which required—gas, water, or steam.

(*c*). Whether to be black, galvanized, or coated with Dr. Angus Smith's composition. Galvanizing is recommended.

Pipes exceeding 2 feet in length (item 1) should be demanded by feet run (not weight), and other items by the numbers required; unless otherwise specified in the indent, straight pipes are supplied in lengths of 10, 11, 12, 13 and 14 feet, the numbers of each length being about equal. A few spare sockets should be demanded to allow for losses and for use with pipes cut on the spot into two or more lengths.

Valves and Cocks.

14. The stop-cocks included (as "main-cocks") in trade lists of wrought-iron pipes are not recommended for use with water pipes unless the pressure is very low, and even then they should not be used with pipes exceeding $1\frac{1}{4}$ inches bore; they can be turned off quickly, and may thus be made to produce violent shocks in the pipes; any that are used should have round-way brass plugs.

Screw-down wheel stop-valves, with cast-iron bodies and gun-metal working parts are recommended in preference to main-cocks; the ends can be flanged or screwed (female); when the ends are screwed, two pipe unions, or two long screws, should be demanded with each valve to allow of easy removal for repairs. The above objection applies to the ordinary bib-cocks, or taps; screw-down bib-taps are preferable; they are generally made of brass or gun-metal, with male ends screwed for iron pipe; when required for connection to lead pipes a "screw boss tinned for lead pipe" should be ordered with each. There are many varieties of screw-down taps; Lord Kelvin's pattern is said to be the most durable, as a slight grinding action takes place between the valve and seat whenever the tap is closed, and the valve and seat are thus kept true.

Most patterns of bib-taps choke the waterway; if a full supply of water be required, it is well to order taps one size larger than the pipes to which they are to be respectively connected, and make the connections with reducing sockets; thus a 1-inch tap might be used with a $\frac{3}{4}$-inch pipe.

Ball valves are supplied with the ends screwed (male) for iron pipe unless they are specified to be flanged. The particulars required for stop-valves, etc., are as follows:—

(i.). For all descriptions, bore of the pipe to which the valve or tap is to be connected.

(ii.). Description of ends for connection to pipes.

(iii.). In the case of ball valves, the pressure against which they are to be effective when closed.

(iv.). Whether the body is to be polished or left rough.

Connections of Wrought-iron Pipes to Cast-iron Pipes.

15. The ordinary method of connecting a wrought-iron pipe to a cast-iron pipe is to drill and tap a hole in the latter, and screw a ferrule into it. The screwed end of the ferrule generally projects into the cast-iron pipe and obstructs the flow in it. When such connections have to be made after the cast-iron pipes are laid, this method is almost the only course practicable; as a rule, the hole in the cast-iron pipe is drilled vertically, so that a ferrule with a quarter-bend has to be used, and the wrought-iron pipe is thus often brought too near the surface of the ground. When the positions of connections between cast-iron and wrought-iron pipes can be foreseen, it is advisable to have a "boss," or thickening patch, cast on the cast-iron pipe (*Fig.* 14, *Plate* I.); the boss can be drilled, tapped and closed with a wrought-iron screw plug by the manufacturer, or it can be left blind for drilling, etc., in India. The provision of a boss is particularly advisable when the bore of the wrought-iron pipe does not differ much from that of the cast-iron pipe to which the connection is to be made.

Wrought-iron pipes can also be connected to the sockets or flanges of cast-iron pipes as follows:—

Bore of Wrought-iron Pipe.	Connection to Cast-iron Socket.	Connection to Cast-iron Flange.
Inches. 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4 ...	Lead joint as for cast-iron pipes of same bores.	As for cast-iron flanged pipes of same bores.
$2\frac{3}{4}$	Attach short length of 3-inch pipe with reducing socket, and connect to 3-inch cast-iron socket with lead joint.	Attach 3-inch flange with 3-inch nipple and reducing socket, bolt to 3-inch cast-iron flange.
$2\frac{1}{4}$	Attach short length of $2\frac{1}{2}$-inch pipe as above, and connect to $2\frac{1}{2}$-inch cast-iron socket with lead joint.	Attach $2\frac{1}{2}$-inch flange with nipple and reducing socket, bolt to $2\frac{1}{2}$-inch cast-iron flange.
Less than 2 ...	Attach short length of 2-inch pipe with reducing socket, and connect to 2-inch cast-iron socket with lead joint.	Attach 2-inch flange with 2-inch nipple and reducing socket, bolt to 2-inch cast-iron flange.

The external surfaces of wrought-iron pipes intended for lead joints may be "jagged" with a cold chisel in order to form a key for the lead.

APPENDIX.

Formulæ for Thickness of Cast-iron Pipes.

The general formula is—

$$t=\frac{\cdot 433hd}{2S}+y,$$

in which t = thickness in inches.

h = static head of water in feet.

d = bore in inches.

S = *average* stress on metal in pounds per square inch.

y = an addition to the calculated thickness, depending on experience.

Particular Formulæ.

(*a*). $t=\cdot 000144hd$ ... ... Latham.

(*b*). $t=\cdot 0001hd+\cdot 25$ ... ... Bateman.

(*c*). $t=\cdot 00006\,(h+230)\,d+\cdot 333\,(1-\cdot 01d)$... Fanning.

(*d*). $t=\cdot 000054hd+\cdot 15\sqrt{d}$ ... ... Molesworth.

The values of S and y in these formulæ are as follows :—

(*a*). S = 1500 ; $y=0$.

(*b*). S = 2165 ; $y=\cdot 25$ inch.

(*c*). S = 3600, but 230 feet are added to h to allow for shocks from the closing of valves, etc.

$y=\cdot 313$ inches for 2-inch pipes and diminishes as the bore increases.

(*d*). S = 4000 ; $y=\cdot 21$ inch for 2-inch pipes and increases with the square root of d.

For pipes subject to very high pressures the following formulæ for thick cylinders may be used :—

(*e*). $$t=\frac{d}{2}\left\{\sqrt{\left(\frac{S+\cdot 433h}{S-\cdot 433h}\right)}-1\right\},$$

in which S = the *limiting* stress in pounds per square inch.

Weights of Cast-iron Pipes.

The average weight of 1 cubic foot of cast iron is 448 lbs., or 4 cwt. ; hence the weight of a lineal foot of any uniform section is $\frac{4}{144}$ or $\frac{1}{36}$ cwt. per square inch of sectional area.

Let d = bore, t = thickness of a pipe—both in inches.

A = area of a circle of diameter $d+2t$.

a = ,, ,, d.

Then the sectional area of the pipe in square inches s $A - a$ or $\pi (d+t) t$, and the weight of a lineal foot in cwt. is—

$$\frac{A - a}{36} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1),$$

or

$$\pi \frac{(d+t)\, t}{36} = \cdot 0873\ (d+t)\, t \ldots\ \ldots\ldots\ldots\ldots\ldots (2).$$

Formula (1) is the simpler if A and a can be found in a table of areas of circles.

The weights given in Table II. have been calculated as above; those given in Table I. are based on the details given in Tables II. and III.

The total weights inserted in indents should include the following additions to "book" or tabular weights :—

4 per cent.	for pipes	not exceeding 7 inches bore.		
3 ,,	,,	exceeding 7 and not exceeding 12 inches bore.		
$2\frac{1}{2}$,,	,,	,, 12	,, ,, 18	,,
2 ,,	,,	,, 18 inches bore.		

The following formula is sufficiently accurate for approximate estimates of total weight of pipes in 9-foot lengths :—

Total weight of L feet in tons $= \cdot 005 \times L\ (d+t)\, t$; this includes an allowance of about 3 per cent. above "book" weights, and assumes that the weight of a socket is equal to that of 1 foot lineal of pipe.

Flow of Water in Clean Pipes Running Full.

Explanation of Tables IV. *to* XIII.

Symbols.

d = bore of pipe in *inches*.

$\frac{d}{48}$ = hydraulic mean depth in *feet*.

g = accelerating force of gravity in feet per second = 32·2.

h = available head of water in feet.*

l = length of axis of pipe in feet—with a minimum of three times the bore, *e.g.*, not less than 3 feet for a 12-inch pipe.

v = velocity of discharge in feet per *second*.

G = discharge in *gallons* per *minute*.

* This term here means the head available for producing the velocity of discharge and for overcoming all resistances in a pipe, *e.g.*, if the head above a certain point were 150 feet and water were required to be delivered at that point under the pressure due to 100 feet head, the "available" head would be 150 − 100 = 50 feet.

Then for a *straight* pipe, of which the bore and form of entry are known—

$$v = C\sqrt{\frac{h}{l+x}},$$

$$G = M\sqrt{\frac{h}{l+x}},$$

when velocity of discharge, resistance of entry, and friction are taken into account; or, when friction only is taken into account—

$$v = C\sqrt{\frac{h}{l}},$$

$$G = M\sqrt{\frac{h}{l}},$$

In these formulæ C and M are factors which are constant for each bore, and x—in feet—is an addition to be made to l when it is necessary to allow for the portions of head required to produce the velocity of discharge and overcome the resistance of entry; x is a constant for each bore and form of entry. The values of x, C, and M for clean pipes from $1\frac{1}{2}$ to 24 inches bore are given in Tables IV., V., and VI. respectively; the details of their computation are as follows:—

Let h_1 = portion of h required to produce velocity v.
h_2 = portion of h required to overcome resistance of entry.
h_3 = portion of h required to overcome friction in pipe, *i.e.*, the "frictional head."

Then

$$h = h_1 + h_2 + h_3 \text{ .... } (1);$$

$$h_1 = \frac{v^2}{2g} \text{ .... } (2);$$

$$h_2 = e\frac{v^2}{2g} \text{ .... } (3);$$

$$h_3 = \frac{48z}{d} \times l \times \frac{v^2}{2g} \text{ .... } (4).$$

In (3) $e = \cdot505$ for cylindrical entry, $\cdot08$ for bell-mouth (*vena contracta*) entry; ends of pipes flush with internal face of reservoir.

In (4) $z = \cdot005\left(1 + \frac{1}{d}\right)$, Darcy's approximate coefficient for *clean** pipes, and $\frac{h_3}{l}$ is the hydraulic gradient or virtual slope.

* For slightly incrusted pipes $z = \cdot01\left(1 + \frac{1}{d}\right)$ or twice its value for clean pipes.—*Darcy*.

From (1) to (4)—

$$h=\left(1+e+\frac{48z}{d}l\right)\frac{v^2}{2g}=\frac{48z}{d}\left(\frac{1+e}{48z}d+l\right)\frac{v^2}{2g} \quad \ldots\ldots\ldots(5).$$

Now from the values of e and z, given above, it will be seen that, for *each* bore, the value of $\frac{1+e}{48z}d\left(=6{\cdot}271\frac{d^2}{d+1}\right.$ for cylindrical entry, and $4{\cdot}5\frac{d^2}{d+1}$ for bell-mouth entry) is constant for any particular form of entry. The value for each bore and form of entry may therefore be tabulated as in Table IV.

Substituting x for

$$\frac{1+e}{48z}d \text{ in (5), } h=\frac{48z}{d}(l+x)\frac{v^2}{2g} \quad \ldots\ldots\ldots\ldots\ldots(6).$$

From (4) and (6)—

$$\frac{h}{l+x}=\frac{h_3}{l} \text{ the hydraulic gradient } \ldots\ldots\ldots\ldots\ldots(7).$$

Hence the portion of head ($h-h_3$ or h_1+h_2) expended in producing the velocity of discharge and overcoming the resistance of entry may be allowed for in calculations by taking h as the head required to overcome friction in a pipe whose length is $l+x$ feet.

From (2) and (3), $h_1+h_2=(1+e)\frac{v^2}{2g}$; therefore, with the velocities usually allowed in long water mains (see the notes following Table V.), the value of h_1+h_2 can rarely amount to more than a small fraction of a foot, and consequently in such cases h_3 differs very little from h; hence, for long pipes, the hydraulic gradient is generally taken as $\frac{h}{l}$ instead of $\frac{h_3}{l}$ or $\frac{h}{l+x}$, *i.e.*, x may generally be neglected when it is small in comparison with l. When, however, a pipe is "short" (say less than 1,000 diameters), x might not be small in comparison with l, so that $\frac{h_3}{l}$ or $\frac{h}{l+x}$ would differ considerably from $\frac{h}{l}$. In the case of short pipes it is, therefore, important that calculations should be based on a hydraulic gradient of $\frac{h}{l+x}$. Thus the discharge from a 12-inch pipe 100 feet long, with cylindrical entry, under a head of 25 feet, would from Tables IV. and VI. be $16011\sqrt{\frac{25}{100+69}} = 6{,}158$ gallons per minute, whereas if x were neglected the discharge would appear to be $16011\sqrt{\frac{25}{100}} = 8{,}005$ gallons.

From (6)—

$$v = \sqrt{\frac{gd}{24z}}\sqrt{\frac{h}{l+x}} = \sqrt{\frac{32{\cdot}2 \times d^2}{24 \times {\cdot}005\ (d+1)}}\sqrt{\frac{h}{l+x}}$$

$$= 16{\cdot}381\frac{d}{\sqrt{d+1}}\sqrt{\frac{h}{l+x}} = \mathrm{C}\sqrt{\frac{h}{l+x}} \quad \ldots\ldots\ldots (8),$$

and

$$\mathrm{G} = 6{\cdot}232^* \times \frac{\pi d^2}{4 \times 144} \times 60v = 2{\cdot}039d^2 \times 16{\cdot}381\frac{d}{\sqrt{d+1}}\sqrt{\frac{h}{l+x}}$$

$$= 33{\cdot}41\frac{d^3}{\sqrt{d+1}}\sqrt{\frac{h}{l+x}} = \mathrm{M}\sqrt{\frac{h}{l+x}} \quad \ldots\ldots\ldots\ldots (9).$$

From the above it will be seen that the expressions for which C and M are respectively substituted in (8) and (9) are constant for each bore; their values may, therefore, be tabulated as in Tables V. and VI.

It should be noted that the tabular values of C and M are for *clean* pipes, and that, if it be desired to apply them to the case of rough or slightly incrusted pipes, they should first be multiplied by $\frac{1}{\sqrt{2}}$ (= ·71 approximately), because for such pipes the coefficient $z = {\cdot}01\left(1+\frac{1}{d}\right)$ or twice its value for clean pipes.

From (7) and (9)—

$$\mathrm{G} = \mathrm{M}\sqrt{\frac{h_3}{l}}.$$

Hence, for a given discharge from a given pipe, the frictional head

$$h_3 = l\,\frac{\mathrm{G}^2}{\mathrm{M}^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10).$$

Table VII., for *clean* pipes, has been calculated from this formula; for rough or slightly incrusted pipes the results should be multiplied by 2, because in their case $\frac{\mathrm{M}}{\sqrt{2}}$ would be substituted for M in (10).

Bends and Knees.—The resistances of bends and knees cause a loss

* 1 cubic foot = 6·232 gallons.

of head which, if considerable, must be deducted from h before the discharge is calculated.

Tables VIII. and IX. give the values of factors, B and K, for determining the loss of head due to bends and knees respectively. Knees should be avoided as much as possible ; bends can generally be substituted for them.

When there are many bends in a pipe, and it is important to economize head, the loss may be reduced by increasing the bores of the bends ; thus if BAv^2 (Table VIII.) be the loss of head for a bend of A degrees in a pipe of bore d, that for a bend of increased bore D would be $BAv^2 \frac{d^4}{D^4}$, provided the ratio of the radius of the bend to the bore were not materially reduced.

Relative Discharges of Pipes of Different Bores.—The relative discharges of two long pipes of different bores *having the same hydraulic gradient* depend on the respective values of M (Table VI.) for the two pipes ; thus if M and m be the values for pipes of bores D and d, their relative discharges will be in the proportion of M to m ; hence, if d be the smaller bore, the number of pipes of bore d whose combined discharge is equal to that of one pipe of bore D is $\frac{M}{m}$. Table X. gives the values of $\frac{M}{m}$ for various values of D and d.

Equivalent Pipes.—An "equivalent" pipe is one which, *with the same head*, gives the same discharge as another pipe of different length and bore, or as a series of pipes of various lengths and bores laid in one line. The discharge from such a series of pipes may, therefore, be found by calculating the discharge from an equivalent pipe of a *given* bore. The length of the equivalent pipe may be found as follows :—

Let *$ldh \ldots\ldots\ldots l_n d_n h_n$ be the series of pipes ; $m \ldots\ldots\ldots m_n$ the respective values of M (Table VI.) ; LDH and M the length, etc., of the equivalent pipe.

Then, since the head on the equivalent pipe is the same as the total head on the series of pipes, $H = h + \ldots\ldots\ldots + h_n$, and since the discharge G is the same in the equivalent pipe and in each pipe of the series—

$$H = L\frac{G^2}{M^2}, \; h = l\frac{G^2}{m^2} \ldots\ldots\ldots h_n = l_n\frac{G^2}{{m_n}^2}.$$

* ldh means a pipe whose length is l feet, and bore d inches, under a head h feet.

Hence

$$L\frac{G^2}{M^2}=l\frac{G^2}{m^2}+\ \ldots\ldots +l_n\frac{G^2}{{m_n}^2},\ \text{and}\ L=l\left(\frac{M}{m}\right)^2+\ \ldots\ldots +l_n\left(\frac{M}{m_n}\right)^2.$$

Table XI. gives the values of $\left(\frac{M}{m}\right)^2$ for various bores.

Jets.—The range and maximum height of a jet may be calculated approximately from the usual formulæ for a projectile in vacuo by multiplying the theoretical velocity ($\sqrt{2gH}$) of discharge from the nozzle by two reducing factors, one (f) depending on the form of the nozzle, and the other (F) on the ratio of the effective head (H) at the nozzle to the bore of the nozzle.

Hence, if θ = angle of elevation of jet,

Range in feet $=(Ff)^2\frac{v^2}{g}\sin 2\theta=2\ (Ff)^2\ H\sin 2\theta.$

Maximum height $=(Ff)^2\frac{v^2}{2g}\sin^2\theta=(Ff)^2\ H\sin^2\theta.$

In Table XII. $N=(Ff)^2$, f being taken at ·97.

The discharge in gallons per minute from a nozzle of diameter $\frac{n}{8}$ inch is $\cdot 248n^2\sqrt{H}$.

Table XIII. includes discharges for given values of H and n, and the corresponding values of NH for calculating ranges and maximum heights.

Table I.

"*Book*" *Weights of Cast-iron Pipes.*

Bore.	Thickness.	Length.	Weight per Length.					
			Plain Spigots and Sockets Drawing 2,781.		Turned and Bored Spigots and Sockets. Drawing 2,782.		Flanged Pipes.	
Inches.	Inch.	Feet.	Cwt.	Cwt. qrs. lbs.	Cwt.	Cwt. qrs. lbs.	Cwt.	Cwt. qrs. lbs.
2	$\frac{3}{8}$	6	0·547	0 2 5	0·554	0 2 6	0·537	0 2 4
2	$\frac{3}{8}$	6	0·656	0 2 18	0·664	0 2 19	0·652	0 2 17
3	$\frac{3}{8}$	9	1·096	1 0 11	1·105	1 0 12	1·090	1 0 10
4	$\frac{3}{8}$	9	1·413	1 1 18	1·423	1 1 20	1·473	1 1 25
5	$\frac{13}{32}$	9	1·885	1 3 15	1·902	1 3 17	1·969	1 3 25
5	$\frac{7}{16}$	9	2·080	2 0 9	2·097	2 0 11	2·112	2 0 13
6	$\frac{7}{16}$	9	2·453	2 1 23	2·474	2 1 25	2·520	2 2 2
7	$\frac{1}{2}$	9	3·220	3 0 25	3·243	3 0 27	3·426	3 1 20
8	$\frac{1}{2}$	9	3·710	3 2 24	3·745	3 2 27	3·862	3 3 13
9	$\frac{9}{16}$	9	4·637	4 2 15	4·676	4 2 20	4·880	4 3 15
10	$\frac{9}{16}$	9	5·115	5 0 13	5·160	5 0 18	5·413	5 1 18
10	$\frac{5}{8}$	9	5·668	5 2 19	5·711	5 2 24	5·962	5 3 24
11	$\frac{5}{8}$	9	6·243	6 0 27	6·284	6 1 4	6·617	6 2 13
12	$\frac{5}{8}$	9	6·774	6 3 3	6·824	6 3 8	7·217	7 0 24
13	$\frac{11}{16}$	9	8·011	8 0 2	8·065	8 0 7	8·456	8 1 23
14	$\frac{11}{16}$	9	8·755	8 3 1	8·824	8 3 8	9·056	9 0 6
15	$\frac{11}{16}$	9	9·344	9 1 11	9·417	9 1 19	9·657	9 2 17
16	$\frac{3}{4}$	9	10·794	10 3 5	10·872	10 3 14	11·270	11 1 2
18	$\frac{3}{4}$	9	12·156	12 0 17	12·239	12 0 27	12·582	12 2 9
20	$\frac{7}{8}$	9	15·717	15 2 24	15·813	15 3 7	16·186	16 0 21

Lengths are exclusive of sockets, but inclusive of flanges.

Weights are inclusive of sockets or flanges.

The dimensions of the flanges are given in the Table of Flanges (page 220).

The weights of pipes differing from the above in thickness or other particulars can be obtained from the details given in Tables II. and III.

Table II.

"Book" Weights of Cast-iron Pipes, exclusive of Sockets or Flanges, in Cwt. per Lineal Foot.

Bore of Pipe in Inches.	Thickness of Pipe in Inches.									
	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$
2 … … … … … …	·0777	—	—	—	—	—	—	—	—	—
2½ … … … … … …	·0941	—	—	—	—	—	—	—	—	—
3 … … … … … …	·1104	·1312	—	—	—	—	—	—	—	—
3½ … … … … … …	·1268	·1503	—	—	—	—	—	—	—	—
4 … … … … … …	·1432	·1694	—	—	—	—	—	—	—	—
4½ … … … … … …	·1595	·1885	·2182	—	—	—	—	—	—	—
5 … … … … … …	—	·2076	·2400	—	—	—	—	—	—	—
5½ … … … … … …	—	·2266	·2618	—	—	—	—	—	—	—
6 … … … … … …	—	·2458	·2836	—	—	—	—	—	—	—
6½ … … … … … …	—	·2649	·3054	·3467	—	—	—	—	—	—
7 … … … … … …	—	·2839	·3273	·3712	—	—	—	—	—	—
7½ … … … … … …	—	·3031	·3491	·3958	—	—	—	—	—	—
8 … … … … … …	—	·3221	·3709	·4203	—	—	—	—	—	—
8½ … … … … … …	—	—	·3927	·4449	·4977	—	—	—	—	—
9 … … … … … …	—	—	·4145	·4694	·5250	·5812	—	—	—	—
9½ … … … … … …	—	—	—	·4939	·5522	·6112	—	—	—	—
10 … … … … … …	—	—	—	·5185	·5795	·6412	—	—	—	—
10½ … … … … … …	—	—	—	·5430	·6068	·6712	—	—	—	—
11 … … … … … …	—	—	—	·5676	·6340	·7012	—	—	—	—
12 … … … … … …	—	—	—	·6167	·6886	·7612	—	—	—	—
13 … … … … … …	—	—	—	·6658	·7431	·8212	·8999	—	—	—
14 … … … … … …	—	—	—	·7148	·7810	·8812	·9654	—	—	—
15 … … … … … …	—	—	—	·7639	·8522	·9412	1·0308	—	—	—
16 … … … … … …	—	—	—	—	·9068	1·0012	1·0963	—	—	—
17 … … … … … …	—	—	—	—	·9613	1·0612	1·1617	—	—	—
18 … … … … … …	—	—	—	—	—	1·1212	1·2272	1·3339	1·4413	—
19 … … … … … …	—	—	—	—	—	—	1·2926	1·4048	1·5176	—
20 … … … … … …	—	—	—	—	—	—	—	1·4757	1·594	1·7130

Table III.

Book" Weights of Sockets and Flanges of Cast-iron Pipes in Cwt.

Bore of Pipe.	Thickness of Pipe.	Plain Spigots and Sockets. Drawing 2,781. Weight per Joint.	* Difference in weight for each difference of $\frac{1}{16}$ inch in thickness of Pipe.	Lead Joint. Depth.	Lead Joint. Weight.	Spun Yarn. Weight.	Turned and Bored Spigots and Sockets. Drawing 2,782. Weight per Joint.	* Difference in Weight for each difference of $\frac{1}{16}$ inch in thickness of pipe.	Lead Joint. Weight.	Weight of Flanges per pair.
Inches.	Inch.	Cwt.	Cwt.	Inches.	Lbs.	Lbs.	Cwt.	Cwt.	Lbs.	Cwt.
2	$\frac{3}{8}$	·0811			1·67	0·18	·0874		1·41	·0709
2½	$\frac{3}{8}$	·0918			1·85	0·21	·0992		1·64	·0874
3	$\frac{3}{8}$	·1025			2·22	0·24	·1109		1·87	·0959
3½	$\frac{3}{8}$	·1132	·0027	1½	2·40	0·27	·1226	·0029	2·10	·1044
4	$\frac{3}{8}$	·1239			2·77	0·30	·1344		2·33	·1845
4½	$\frac{3}{8}$	·1346			2·95	0·33	·1461		2·56	·1957
5	$\frac{7}{16}$	·2118			5·73	0·64	·2290		4·48	·2432
5½	$\frac{7}{16}$	·2265			6·18	0·69	·2452		4·83	·2557
6	$\frac{7}{16}$	·2412			6·64	0·75	·2613		5·19	·3074
6½	$\frac{7}{16}$	·2560	·0037	1¾	7·09	0·80	·2775	·0041	5·54	·3646
7	$\frac{1}{2}$	·2739			7·66	0·86	·2977		5·99	·4799
7½	$\frac{1}{2}$	·2886			8·12	0·92	·3138		6·34	·5018
8	$\frac{1}{2}$	·3723			9·71	1·10	·4067		7·83	·5236
8½	$\frac{1}{2}$	·3902			10·23	1·16	·4264		8·24	·5454
9	$\frac{9}{16}$	·4126			10·87	1·24	·4511		8·76	·6557
9½	$\frac{9}{16}$	·4244	·0045	2	11·39	1·30	·4708	·0049	9·18	·6804
10	$\frac{5}{8}$	·4529			12·03	1·37	·4955		9·62	·7464
10½	$\frac{5}{8}$	·4647			12·55	1·43	·5152		10·03	·7606
11	$\frac{5}{8}$	·5373			13·07	1·49	·5835		10·45	·9108
12	$\frac{5}{8}$	·5764	·0049		14·10	1·61	·6262	·0054	11·28	1·020
13	$\frac{11}{16}$	·6204			15·22	1·74	·6744		12·30	1·065
14	$\frac{11}{16}$	·8244			19·54	2·09	·8928		16·38	1·125
15	$\frac{11}{16}$	·8729	·0061		20·77	2·22	·9457	·0066	17·41	1·186
16	$\frac{3}{4}$	·9276			22·16	2·37	1·0052		18·58	1·403
17	$\frac{3}{4}$	1·0555	·0066	2¼	23·40	2·50	1·1347	·0071	19·61	1·470
18	$\frac{3}{4}$	1·1079			24·63	2·63	1·1914		20·65	1·537
19	$\frac{3}{4}$	1·2959			25·87	2·77	1·3863		21·68	1·819
20	$\frac{7}{8}$	1·3682	·0073		27·42	2·93	1·4641	·0078	22·98	1·840

* *Example.*—Weight of plain socket, etc., of 5″ pipe $\frac{13}{32}$″ thick = ·2118 – ½ × ·0037 = ·21 cwt.
" " " " 10″ " $\frac{9}{16}$″ " = ·4529 – ·0045 = ·4484 cwt.

TABLE IV.

Values of x *in* $\frac{h}{l+x}$ (*for* Clean *Pipes*). *See Tables V. and VI.*

Note.—When $\frac{h}{l+x}$ is used in calculations the actual values of h and l must be inserted, and not their ratio merely; *e.g.*, for a pipe 500 feet long, with a head of 10 feet, $\frac{h}{l+x} = \frac{10}{500+x}$, and not $\frac{1}{50+x}$.

d	x		d	x		d	x	
Bore of Pipe.	Form of Entry.		Bore of Pipe.	Form of Entry.		Bore of Pipe.	Form of Entry.	
	Cylindrical.	Bell-mouth.		Cylindrical.	Bell-mouth.		Cylindrical.	Bell-mouth.
Inches.	Feet.	Feet.	Inches.	Feet.	Feet.	Inches.	Feet.	Feet.
1½	6	4	7	38	28	14	82	59
2	8	6	7	42	30	15	88	63
2½	11	8	8	45	32	16	94	68
3	14	10	8½	48	34	17	101	72
3½	17	12	9	51	36	18	107	77
4	20	14	9½	54	39	19	113	81
4½	23	16	10	57	41	20	119	86
5	26	18	10½	60	43	21	126	90
5½	29	21	11	63	45	22	132	95
6	32	23	12	69	50	23	138	99
6½	35	25	13	76	54	24	144	104

For bores not included in this table the respective values of x in feet may be calculated from

$$x = \frac{d^2}{d+1} \times \begin{cases} 6{\cdot}271 \text{ for pipes with cylindrical entry.} \\ 4{\cdot}5 \quad \text{,,} \quad \text{,,} \quad \text{bell-mouth} \quad \text{,,} \end{cases}$$

Note.—In calculations for rough or slightly incrusted pipes, take *half* of the above values of x.

Table V.

Values of C for calculation of Velocities in feet per second, for Clean *Pipes flowing full, from* $v = C\sqrt{\frac{h}{l+x}}$ *(for "short" Pipes,* i.e., *length from* 3 *times to* 1,000 *times the bore), or from* $v = C\sqrt{\frac{h}{l}}$ *(for "long" Pipes, i.e., length exceeding* 1,000 *times the bore). For values of* x, *see Table IV.*

d Bore of Pipe.	C	*d* Bore of Pipe.	C	*d* Bore of Pipe.	C	*d* Bore of Pipe.	C
Inches.		Inches.		Inches.		Inches.	
1½	15·54	6	37·15	10½	50·72	19	69·59
2	18·92	6½	38·88	11	52·02	20	71·49
2½	21·89	7	40·54	12	54·52	21	73·34
3	24·57	7½	42·14	13	56·91	22	75·14
3½	27·03	8	43·68	14	59·21	23	76·91
4	29·30	8½	45·18	15	61·43	24	78·63
4½	31·43	9	46·62	16	63·57		
5	33·44	9½	48·03	17	65·64		
5½	35·34	10	49·39	18	67·64		

For bores not included in this table the respective values of C may be found from $C = \frac{d}{\sqrt{d+1}} \times 16{\cdot}381$.

For any long pipe $C = v\sqrt{\frac{l}{h}}$; hence, when v, h, and l are given, d may be approximately determined from the table as follows:— Find the tabular value of C most nearly agreeing with $v\sqrt{\frac{l}{h}}$, then a pipe of the bore corresponding to the tabular value of C will nearly meet the requirements; *e.g.*, if $v = 4$, $h = 10$, and $l = 1{,}000$, then $v\sqrt{\frac{l}{h}} = 40$, and the nearest tabular value of C is 40·54, hence $d = 7$ inches. If the value of C found from $v\sqrt{\frac{l}{h}}$ be beyond the range of the table, d may be found from

$$\frac{d^2}{d+1} = C^2 \times {\cdot}00373.$$

When v, l, and d are given, $h=(l+x)\frac{v^2}{C^2}$ for a short pipe, or $l\frac{v^2}{C^2}$ for a long pipe; in the case of a long pipe, h thus found is the frictional head.

The equations connecting v, d, and G (the discharge in gallons per minute) are, very approximately, $G=vd^2\times 2{\cdot}04$, $v=\frac{G}{d^2}\times{\cdot}49$, and $d={\cdot}7\sqrt{\frac{G}{v}}$.

The maxima velocities of flow generally allowed in water mains are as follows (*Fanning*):—

Bore, inches	4	6	8	10	12	14	16	18	20	22	24	27	30	33	36
Velocity, feet per second	2·5	2·8	3	3·3	3·5	3·9	4·2	4·5	4·7	5	5·3	5·8	6·2	6·6	7

Note.—In calculations for rough or slightly incrusted pipes, the tabular values of C should be multiplied by $\frac{1}{\sqrt{2}}$ ($={\cdot}71$ approximately).

TABLE VI.

Values of M for calculation of Discharges in gallons per minute, *for* Clean *Pipes flowing full, from* $G=M\sqrt{\frac{h}{l+x}}$ *(short Pipes), or from* $G=M\sqrt{\frac{h}{l}}$ *(long Pipes). For values of* x, *see Table IV.*

d Bore of Pipe.	M	*d* Bore of Pipe.	M	*d* Bore of Pipe.	M	*d* Bore of Pipe.	M
Inches.		Inches.		Inches.		Inches.	
1½	71	6	2,727	10½	11,404	19	51,238
2	154	6½	3,350	11	12,836	20	58,321
2½	279	7	4,051	12	16,011	21	65,961
3	451	7½	4,834	13	19,616	22	74,173
3½	675	8	5,702	14	23,669	23	82,970
4	956	8½	6,656	15	28,187	24	92,365
4½	1,298	9	7,701	16	33,188		
5	1,705	9½	8,839	17	38,686		
5½	2,180	10	10,073	18	44,698		

For bores not included in this table the respective values of M may be found from $M = \frac{d^3}{\sqrt{d+1}} \times 33{\cdot}41$.

For any long pipe $M = G\sqrt{\frac{l}{h}}$; hence, when G, h, and l are given, d may be approximately determined from the table as follows:—Find the tabular value of M most nearly agreeing with $G\sqrt{\frac{l}{h}}$, then a pipe of the bore corresponding to the tabular value of M will nearly give the required discharge. If the pipe be "short," find the tabular value of M which most nearly exceeds $G\sqrt{\frac{l}{h}}$, and then calculate the discharge from $M\sqrt{\frac{h}{l+x}}$; if the discharge prove insufficient the next higher value of M must be tried; *e.g.*, if $G = 6{,}000$, $h = 25$, and $l = 100$, then $G\sqrt{\frac{l}{h}} = 12{,}000$, and the next higher tabular value of M is 12,836, hence the pipe cannot be less than 11 inches bore, and is evidently "short," *i.e.*, length less than 1,000 times the bore; if the entry be cylindrical $x = 63$ for 11 inches bore (Table IV.), and $G = 12{,}836\sqrt{\frac{25}{100+63}} = 5{,}027$, which is insufficient; for 12 inches bore,

$$x = 69 \text{ and } G = 16011\sqrt{\frac{25}{100+69}} = 6158,$$

which is sufficient, hence $d = 12$ inches nearly. If the value of M, found from $G\sqrt{\frac{l}{h}}$ be beyond the range of the table, d for a *long* pipe may be found roughly from $d^5 = M^2 \times {\cdot}00282$.

When G, l, and d are given, $h = (l+x)\frac{G^2}{M^2}$ for a short pipe, or $l\frac{G^2}{M^2}$ for a long pipe; in the case of a long pipe, h thus found is the frictional head.

Note.—In calculations for rough or slightly incrusted pipes the tabular values of M should be multiplied by $\frac{1}{\sqrt{2}}$ ($= {\cdot}71$ approximately.

Table VII.

Friction in Clean Pipes.

Frictional Head in Feet per 100 Feet Lineal of Pipe for given Discharges.

Given Discharge in Gallons per Minute – G.

d Bore of Pipe in Inches.	10	15	20	25	30	40	50	60	70	80	90	100	125	150	175
1½	1·97	4·42	7·87	12·29	—	—	—	—	—	—	—	—	—	—	—
2	—	·95	1·68	2·63	3·76	6·72	10 50	15·12	20·58	26·88	—	—	—	—	—
2½	—	—	·51	·80	1·16	2·06	3·21	4·62	6·29	8·22	10·40	12·84	—	—	—
3	—	—	—	·31	·44	·79	1·23	1·67	2·41	3·15	3·98	4·92	7·68	11·06	15·06
3½	—	—	—	—	—	·35	·55	·79	1·07	1·40	1·78	2·19	3·43	4·94	6·72
4	—	—	—	—	—	—	·27	·39	·54	·70	·89	1·09	1·71	2·46	3·35

Given Discharge in Gallons per Minute – G.

d Bore of Pipe in Inches.	100	200	300	400	500	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500
5	·34	1·38	3·10	5·51	8·60	—	—	—	—	—	—	—	—	—	—
6	—	·54	1·21	2·15	3·34	4·84	6·59	—	—	—	—	—	—	—	—
7	—	—	·55	·97	1·52	2·19	2·99	3·90	4·94	6·09	—	—	—	—	—
8	—	—	—	·49	·77	1·11	1·51	1·97	2·49	3·08	3·72	4·43	—	—	—
9	—	—	—	—	·42	·61	·83	1·08	1·37	1·69	2·04	2·43	2·85	—	—
10	—	—	—	—	—	·35	·48	·63	·80	·99	1·20	1·42	1·67	1·93	2·22

Table VII.—(*continued*).

Friction in Clean Pipes.

d Bore of Pipe in Inches.	Frictional Head in Feet per 100 Feet Lineal of Pipe for given Discharges.														
	Given Discharge in Gallons per Minute – G.														
	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000	2,100	2,200	2,300	2,400	2,500
11	·73	·87	1·03	1·19	1·37	1·55	1·75	1·97	—	—	—	—	—	—	—
12	·47	·56	·66	·76	·88	1·00	1·13	1·26	—	—	—	—	—	—	—
13	--	·37	·44	·51	·59	·67	·75	·84	·94	1·04	1·15	1·26	1·38	1·50	—
14	—	—	·30	·35	·40	·46	·52	·58	·64	·71	·79	·86	·94	1·03	—
15	—	—	—	·25	·28	·32	36	·41	·45	·50	·56	·61	·67	·73	·79
	Given Discharge in Gallons per Minute – G.														
	3,000	4,000	7,000	9,000	10,000	11,000	12,000	13,000	15,000	16,000	17,000	19,000	21,000	23,000	25,000
16	·82	1·45	4·45	7·35	9·08	10·99	13·07	15·34	20·43	23·25	26·24	32·78	40·04	48·03	57·01
17	·60	1·07	3·27	5·41	6·68	8·08	9·62	11·29	15·03	17·11	19·31	24·12	29·40	35·35	41·76
18	·45	·80	2·45	4·05	5·01	6·06	7·21	8·46	11·26	12·81	14·47	18·07	22·08	26·48	31·28
19	·34	·61	1·87	3·09	3·81	4·61	5·49	6·44	8·57	9·75	11·01	13·75	16·80	20·15	23·81
20	·26	·47	1·44	2·38	2·94	3·56	4·23	4·97	6·62	7·53	8·50	10·61	12·97	15·55	18·38
21	·21	·37	1·13	1·86	2·30	2·78	3·31	3·88	5·17	5·88	6·64	8·30	10·14	12·16	14·36
22	·16	·29	·89	1·47	1·82	2·20	2·62	3·07	4·09	4·65	5·25	6·56	8·02	9·61	11·36
23	·13	·23	·71	1·18	1·45	1·76	2·09	2·45	3·27	3·72	4·20	5·24	6·41	7·68	9·08
24	·11	·19	·57	·95	1·17	1·42	1·69	1·98	2·64	3·00	3·39	4·23	5·17	6·20	7·33

The frictional head for a discharge not included in Table VII. may be found from the proportion of its square to that of a given discharge from a pipe of the same bore; thus, for a discharge of 4,500 gallons per minute from an 18-inch pipe, the frictional head per 100 feet lineal of pipe is $\left(\frac{4500}{9000}\right)^2 \times 4{\cdot}05$ or 1·01 feet.

For pipes of bores not included in Table VII., but included in Table VI., the frictional head per 100 feet lineal of pipe for a given discharge may be found from $100\,\frac{G^2}{M^2}$, and for pipes of any bore d—in inches—from $\frac{G^2\,(d+1)}{d^6} \times {\cdot}0896$.

Note.—The frictional head in a rough or slightly incrusted pipe is double that in a clean pipe of the same bore for the same given discharge.

Table VIII.

Loss of Head due to Bends.

Loss in feet $= BAv^2$.

A = number of degrees in arc—measured at centre of arc.

v = velocity in feet per second in a straight pipe.

$\frac{\text{Radius of Bend}}{\text{Bore of Pipe}} = r$.	B.
1	·000025
1·25...	·000018
1·5	·000015
2	·000013
3	·000012
4 and upwards ...	·000011

For any ratio r—of radius of bend to bore of pipe—

$$B = \cdot0000113 + \cdot000014 \left(\frac{1}{r}\right)^{\frac{7}{2}}$$

Table IX.

Loss of Head due to Knees.

Loss in feet $= Kv^2$.

v = velocity in feet per second in a straight pipe.

Angle.	10°.	20°.	30°.	40°.	50°.	60°.	70°.	80°.	90°.
K ...	·0001	·0005	·0011	·0022	·0036	·0056	·0083	·0115	·0152

For any angle A, $K = \cdot0147 \sin^2 \frac{A}{2} + \cdot0318 \sin^4 \frac{A}{2}$. The angle is measured as for a bend (*Fig.* 1, *Plate* I.).

Table X.

Relative Discharges of Long Pipes of different Bores having the same Hydraulic Gradient.

Bore of Larger Pipe in Inches.	Number of Smaller Pipes of any one Bore giving the same Discharge as one Larger Pipe. Bores of Smaller Pipes in Inches.														
	1½	2	2½	3	3½	4	5	6	7	8	9	10	11	12	13
2	2·16	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2½	3·91	1·81	—	—	—	—	—	—	—	—	—	—	—	—	—
3	6·32	2·92	1·62	—	—	—	—	—	—	—	—	—	—	—	—
3½	9·47	4·37	2·42	1·50	—	—	—	—	—	—	—	—	—	—	—
4	13·41	6·20	3·43	2·12	1·42	—	—	—	—	—	—	—	—	—	—
5	—	11·05	6·11	3·78	2·52	1·78	—	—	—	—	—	—	—	—	—
6	—	17·67	9·77	6·05	4·04	2·85	1·60	—	—	—	—	—	—	—	—
7	—	—	14·52	8·98	6·00	4·24	2·37	1·48	—	—	—	—	—	—	—
8	—	—	—	12·64	8·44	5·96	3·34	2·09	1·41	—	—	—	—	—	—
9	—	—	—	17·08	11·40	8·05	4·52	2·82	1·90	1·35	—	—	—	—	—
10	—	—	—	—	—	10·53	5·91	3·69	2·48	1·76	1·31	—	—	—	—
11	—	—	—	—	—	13·42	7·53	4·70	3·17	2·25	1·67	1·27	—	—	—
12	—	—	—	—	—	16·74	9·39	5·87	3·95	2·81	2·08	1·59	1·25	—	—
13	—	—	—	—	—	—	11·50	7·19	4·84	3·40	2·55	1·95	1·53	1·22	—
14	—	—	—	—	—	—	13·88	8·68	5·84	4 15	3·07	2·35	1·84	1·48	1·20

TABLE X.—(*continued*).

Relative Discharges of Long Pipes of different Bores having the same Hydraulic Gradient.

Bore of Larger Pipe in Inches.	Number of Smaller Pipes of any one Bore giving the same Discharge as one Larger Pipe. Bores of Smaller Pipes in Inches.														
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
15	6·96	4·94	3·66	2·80	2·19	1·76	1·44	1·19	—	—	—	—	—	—	—
16	8·19	5·82	4·31	3·29	2·58	2·07	1·69	1·40	1·18	—	—	—	—	—	—
17	9·55	6·78	5·02	3·84	3·01	2·41	1·97	1·63	1·37	1·16	—	—	—	—	—
18	—	—	5·80	4·44	3·48	2·79	2·28	1·89	1·58	1·34	1·15	—	—	—	—
19	—	—	6·65	5·08	3·99	3·20	2·61	2·16	1·82	1·54	1·32	1·14	—	—	—
20	—	—	—	5·79	4·54	3·64	2·97	2·46	2·07	1·76	1·51	1·30	1·14	—	—
21	—	—	—	6·55	5·14	4·12	3·36	2·79	2·34	1·99	1·70	1·47	1·29	1·13	—
22	—	—	—	—	5·78	4·63	3·78	3·13	2·63	2·23	1·92	1·66	1·45	1·27	1·12
23	—	—	—	—	6·46	5·18	4·23	3·50	2·94	2·50	2·14	1·85	1·62	1·42	1·26
24	—	—	—	—	7·19	5·77	4·71	3·90	3·28	2·78	2·39	2·06	1·80	1·58	1·40

Example.—The discharge from six $3\frac{1}{2}$-inch pipes is the same as that from one 7-inch pipe having the same hydraulic gradient as the $3\frac{1}{2}$-inch pipes.

For any two bores, D (larger) and d (smaller), not given in the table the number of smaller pipes may be found from $\frac{D^3}{d^3}\sqrt{\frac{d+1}{D+1}}$.

TABLE XI.

Equivalent Pipes.

Bore of Larger Pipe in Inches.	Factors for Converting the Lengths of Smaller Pipes into "Equivalent" Lengths of a Larger Pipe.														
	Bores of Smaller Pipes in Inches.														
	1½	2	2½	3	3½	4	5	6	7	8	9	10	11	12	13
2	4·68	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2½	15·31	3·27	—	—	—	—	—	—	—	—	—	—	—	—	—
3	40·00	8·54	2·61	—	—	—	—	—	—	—	—	—	—	—	—
3½	89·66	19·15	5·85	2·24	—	—	—	—	—	—	—	—	—	—	—
4	179·8	38·40	11·74	4·49	2·00	—	—	—	—	—	—	—	—	—	—
5	—	122·07	37·33	14·29	6·37	3·18	—	—	—	—	—	—	—	—	—
6	—	312·43	95·55	36·57	16·31	8·13	2·56	—	—	—	—	—	—	—	—
7	—	—	210·83	80·69	36·00	17·95	5·65	2·20	—	—	—	—	—	—	—
8	—	—	—	159·82	71·30	35·55	11·18	4·37	1·98	—	—	—	—	—	—
9	—	—	—	291·60	130·10	64·87	20·41	7·97	3·61	1·82	—	—	—	—	—
10	—	—	—	—	—	110·57	34·91	13·64	6·18	3·12	1·71	—	—	—	—
11	—	—	—	—	—	180·21	56·69	22·15	10·04	5·07	2·78	1·62	—	—	—
12	—	—	—	—	—	280·38	88·20	34·46	15·62	7·88	4·32	2·52	1·55	—	—
13	—	—	—	—	—	—	132·39	51·73	23·44	11·84	6·49	3·79	2·33	1·50	—
14	—	—	—	—	—	—	192·75	75·31	34·13	17·23	9·44	5·52	3·40	2·18	1·45

TABLE XI.—(*continued*).

Equivalent Pipes.

Bore of Larger Pipe in Inches.	Factors for Converting the Lengths of Smaller Pipes into "Equivalent" Lengths of a Larger Pipe.														
	Bores of Smaller Pipes in Inches.														
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
15	48·41	24·44	13·39	7·83	4·82	3·10	2·06	1·42	—	—	—	—	—	—	—
16	67·11	33·88	18·57	10·85	6·68	4·29	2·86	1·96	1·38	—	—	—	—	—	—
17	91·18	46·04	25·41	14·75	9·08	5·84	3·89	2·67	1·88	1·36	—	—	—	—	—
18	—	—	33·68	19·69	12·12	7·79	5·19	3·56	2·51	1·81	1·33	—	—	—	—
19	—	—	44·26	25·87	15·93	10·24	6·82	4·68	3·30	2·38	1·75	1·31	—	—	—
20	—	—	—	33·52	20·64	13·27	8·84	6·07	4·28	3·09	2·27	1·70	1·30	—	—
21	—	—	—	42·88	26·41	16·97	11·31	7·76	5·47	3·95	2·91	2·18	1·66	1·28	—
22	—	—	—	—	33·31	21·46	14·30	9·82	6·92	4·99	3·67	2·75	2·09	1·62	1·26
23	—	—	—	—	41·78	26·85	17·89	12·29	8·66	6·25	4·60	3·44	2·62	2·02	1·58
24	—	—	—	—	51·78	33·28	22·17	15·22	10·74	7·74	5·70	4·27	3·25	2·51	1·96

For any two bores, D (larger) and d (smaller), not given in the table, the factor may be found from $\frac{D^6}{d^6} \times \frac{d+1}{D+1}$, or from $\frac{M^2}{m^2}$ if the bores are included in Table VI., and M m are the corresponding values of M.

Examples of the Use of this Table.

(i.). Required, G, the discharge in gallons per minute, from a series of pipes consisting of 1,000 feet of 10-inch bore, 500 feet of 8-inch bore, and 500 feet of 6 inch bore, with a head of 20 feet.

From Table XI. the equivalent length of a 10-inch pipe

$$= 1000 + 500 \times 3{\cdot}12 + 500 \times 13{\cdot}64 = 9{,}380 \text{ feet.}$$

From Table VI., for a 10-inch pipe 9,380 feet long, with a head of 20 feet—$G = 10073 \times \sqrt{\frac{20}{9380}} = 465$ gallons.

If the 6-inch pipe were the discharging pipe, the velocity of discharge would be $\frac{465}{6^2} \times {\cdot}49 = 6{\cdot}33$ feet per second (see the notes following Table V.), and the corresponding head is $\frac{(6{\cdot}33)^2}{2g}$ or $0{\cdot}62$ foot; as this amount is considerable, G should be re-calculated for a head of $(20 - 0{\cdot}6) = 19{\cdot}4$ feet, *i.e.*, $G = 10073 \times \sqrt{\frac{19{\cdot}4}{9380}} = 458$ gallons.

(*Note.*—Any bore may be selected for the equivalent pipe, but it is always convenient to adopt the bore of the largest pipe in the series; the use of the reciprocals of the tabular factors is thus avoided).

(ii.). An alteration of route between two points in an existing pipe allows a pipe 1,200 feet long to be substituted for a 12-inch pipe 2,000 feet long. Required the bore of the new pipe.

Let k be the tabular factor.

Then $2000 = 1200 \times k$ or $k = 1{\cdot}67$.

The tabular factor nearest to 1·67 and *opposite a "larger"* pipe of 12 inches bore is 1·55, which occurs in the column for smaller pipes of 11 inches bore; hence the bore of the new and shorter pipe should be 11 inches.

If the conditions were reversed, *i.e.*, if the bore and length of the existing pipe were 12 inches and 1,200 feet respectively, and the length of the new pipe were 2,000 feet, then $k = 1{\cdot}67$ as before; this vâlue, in the *column of "smaller"* pipes of 12 inches bore, lies between 1·50 and 2·18, which occur opposite "larger" pipes of 13 and 14 inches bore respectively; hence the bore of the new and longer pipe should be 14 inches.

Table XII.

Values of N for Calculating the Range and Maximum Height of a Jet in Air.

H = effective head at nozzle, in feet.
n = bore of nozzle, *in eighths of an inch.*
θ = angle of elevation of jet.
Range in feet = 2 NH sin 2θ.
Maximum height = NH $\sin^2\theta$.

When the jet is vertical the height from this formula would be NH, but the water falling back would make the actual height less.

$\frac{H}{n}$	3	4	5	6	7	8	9	10	15	20	25	30	35	40	45
N	·91	·89	·88	·86	·85	·83	·82	·81	·74	·67	·61	·55	·49	·38	·27

Example.—If H = 40, $n = 5$, *i.e.*, bore of nozzle = $\frac{5}{8}$ inch, and $\theta = 45°$; then, since $\frac{H}{n} = \frac{40}{5}$ or 8, N = ·83, and

$$\text{Range} = 2 \times \cdot 83 \times 40 \times 1 = 66{\cdot}4 \text{ feet.}$$

$$\text{Height} = \cdot 83 \times 40 \times \frac{1}{2} = 16{\cdot}6 \text{ feet.}$$

Table XIII.

Discharges (G) in Gallons per Minute and Values of NH for Given Values of H (Effective Head at Nozzle) and Given Bores of Nozzles.

Bore of Nozzle.	3/8 inch.		1/2 inch.		5/8 inch.		3/4 inch.		7/8 inch.		1 inch.	
H.	G.	NH.	G.	NH.	G.	NH.	G.	NH.	G.	NH.	G.	NH.
30	12	24·3	22	25·2	34	25·8	49	26·4	67	26·6	87	26·9
40	14	30·6	25	32·4	39	33·2	56	34·1	77	34·6	100	35·2
50	16	35·8	28	38·8	44	40·5	63	41·3	86	42·4	112	42·9
60	17	40·2	31	44·4	48	46·9	69	48·6	94	49·5	123	50·4
70	19	44·1	33	49·4	52	52·8	75	55·1	102	56·7	133	57·6
80	20	47·2	35	53·6	55	58·1	80	61·0	109	63·2	142	64·8
90	21	49·5	38	57·6	59	62·8	85	66·6	115	69·3	151	71·3
100	22	51·0	40	61·0	62	67·0	89	71·7	122	75·0	159	77·5
120	—	—	43	66·0	68	74·6	98	80·4	133	85·2	174	88·8
140	—	—	47	68·6	73	80·4	106	87·6	144	93·8	188	98·7
160	—	—	—	—	78	84·2	113	94·4	154	101·8	201	107·2
180	—	—	—	—	—	—	120	99·0	163	108·3	213	115·2
200	—	—	—	—	—	—	126	102·0	172	113·4	225	122·0

Specification of Cast-Iron Piping, Etc.

1. The iron is to be of the best quality, grey pig, re-melted in the cupola. It must be of such a quality that a bar of the same 1 inch broad and 2 inches deep, placed on edge on bearings 3 feet apart, shall not break with a less load than 30 cwt. suspended in the centre. Two test bars are to be made from each day's melting, one of which is to be tested by the examiner, and, should it break with any load less than 30 cwt., all castings made with that metal will be rejected. The other test bar is to be marked with the date of casting, and put away for the subsequent inspection of the Superintendent, India Store Depôt, or forwarded to him if he so directs.

2. The castings are to be free from air or sand holes, cinder, or other defects, and are to be cast with a sufficient head of metal to ensure solidity.

3. The straight pipes are to be cast socket downwards in dry sand moulds; the other forms are likewise to be cast in dry sand moulds, and, so far as their shapes permit, socket downwards; alternative tenders will, however, be considered for straight pipes and other forms of *less* than 3 inches bore cast in green sand "on the bank" at an angle of 45 degrees, but when such casting is allowed buttons are to be cast at the ends of any chaplets or core nails that may be used. Chaplets and core nails to be screwed. The bore and thickness of metal are to be uniform throughout. Any casting which is found to be $\frac{1}{16}$ inch or more out of the centre will be rejected.

4. The castings are to be tested in the presence of an officer of the India Store Depôt to an internal pressure of 260 lbs. per square inch; such pressure shall be maintained for at least three minutes whilst the casting is being struck in every part with a suitable hammer; any casting which fails to pass this test will at once be rejected.

5. The contractor is to provide the necessary hydraulic apparatus, and carry out the test at his own expense; the pressure gauges shall, if so required, be sent to the India Store Depôt, Belvedere Road, Lambeth, S.E., for testing and marking, and no others shall be used without the permission in writing of the Superintendent, India Store Depôt.

6. Each casting is to have such marks and letters as may be specified in the schedule cast on the socket or other convenient part, in Roman characters, 1 inch long, and $\frac{1}{8}$-inch projection, and in the event of any being rejected, the marks and letters are immediately to be chipped off in the presence of the examiner.

7. The castings, when approved, are to be cleansed from dirt and rust, and coated inside and out with Dr. Angus Smith's composition.

8. The length and weights are to be as detailed in the schedule. The schedule weights include allowances, detailed below, above the "book" weights, and show the maximum weight of any particular size for which payment will be made. Payment will not, however, be made for more than the actual weights supplied.

Where the schedule weights are omitted in the invitation to tender they are to be *inserted by the tenderer*, and are to include any percentage beyond his calculated weights that he may consider necessary. These weights will be subject to the above conditions as to payment.

The allowances are as follows:—

In pipes 20 to 33 inches bore...	2 per cent.
" 13 " 18 " "	$2\frac{1}{2}$ "
" 8 " 12 " "	3 "
" 2 " 7 " "	4 "

Pipes which fall below the minimum weights, *i.e.*, "book" weight less allowance, may be rejected on this account only.

9. The sockets are to be cast as shown in the drawing or drawings quoted in the schedule (No. 2781 for plain sockets; No. 2782 for turned and bored joints) and the flanges to the dimensions shown in the table of flanges. Bends and other forms of special dimensions are to be cast as shown in any special drawing quoted in the schedule; the thickness of metal in them and in their sockets or flanges is to be the same as in the corresponding parts of straight pipes of the same bore, unless otherwise specified in the schedule.

10. The flanges are to have faced strips, and to be drilled for bolts unless otherwise specified in the schedule. The necessary bolts and nuts for connections are to be supplied, with 2 per cent. of each size spare in addition. The bolts to be of sufficient lengths to show two threads clear of nuts when screwed up. After approval, they are to be coated with boiled linseed oil, and packed by sizes in bags of about 1 cwt. net, which are again to be packed in strong cases or casks.

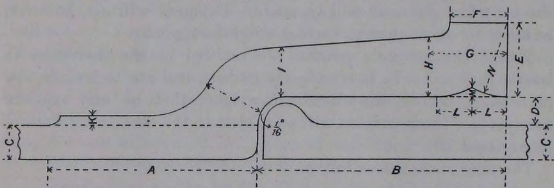
11. Each casting, unless otherwise directed, may be shipped loose.

12. Ten per cent. of the castings are to have stencilled on them the address, and such shipping marks as the Superintendent, India Store Depôt, may direct. Stencil plates are to be provided by the contractor.

13. The cost of all marking, coating, etc., and delivery, is to be included in the sum named in the tender.

I.S.D. Drawing No. 2781.

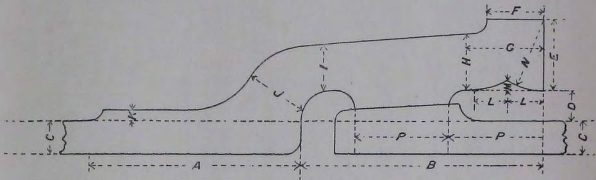
Sketch and Table showing Dimensions in Inches of Plain Joints for Cast-Iron Pipes, with Recess for Lead.



Bore. Inches.	A	B	C Thickness of Pipe.	D	E	F	G	H	I	J	K	L	M	N Radius.
2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$	$2\frac{1}{2}$	3		$\frac{1}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	1	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{16}$
5, $5\frac{1}{2}$, 6, $6\frac{1}{2}$, 7, $7\frac{1}{2}$	3	$3\frac{1}{2}$		$\frac{3}{8}$	1	$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{16}$
8, $8\frac{1}{2}$, 9, $9\frac{1}{2}$, 10, $10\frac{1}{2}$	3	4		$\frac{3}{8}$	$1\frac{1}{8}$	1	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	1	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{16}$
11, 12, 13	3	4		$\frac{3}{8}$	$1\frac{1}{4}$	1	$1\frac{3}{8}$	$\frac{15}{16}$	$\frac{13}{16}$	$1\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{61}$
14, 15, 16	$3\frac{1}{2}$	$4\frac{1}{2}$		$\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{1}{16}$	$\frac{15}{16}$	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	$1\frac{13}{32}$
17, 18	$3\frac{1}{2}$	$4\frac{1}{2}$		$\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{1}{8}$	1	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	$1\frac{13}{32}$
19, 20	$3\frac{1}{2}$	$4\frac{1}{2}$		$\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{3}{8}$	2	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	$1\frac{13}{32}$

I.S.D. Drawing No 2782.

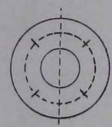
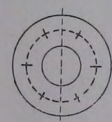
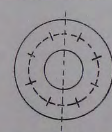
Sketch and Table Showing Dimensions in Inches of Turned and Bored Joints for Cast-iron Pipes, with Recess for Lead.



Bore in Inches.	A	B	C Thickness of Pipe.	D	E	F	G	H	I	J	K	L	M	N Radius.	P
2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, 4, $4\frac{1}{2}$	$2\frac{1}{2}$	3		$\frac{1}{4}$	$\frac{7}{8}$	$\frac{3}{4}$	1	$\frac{11}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{1}{4}$
5, $5\frac{1}{2}$, 6, 6, 7, $7\frac{1}{2}$	3	3		$\frac{3}{8}$	1	$\frac{7}{8}$	$1\frac{1}{8}$	$\frac{13}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{3}{8}$
8, $8\frac{1}{2}$, 9, $9\frac{1}{2}$, 10, $10\frac{1}{2}$	3	4		$\frac{3}{8}$	$1\frac{1}{8}$	1	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	1	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{5}{8}$
11, 12, 13	3	4		$\frac{3}{8}$	$1\frac{1}{4}$	1	$1\frac{3}{8}$	$\frac{15}{16}$	$\frac{13}{16}$	$1\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$1\frac{1}{16}$	$1\frac{5}{8}$
14, 15, 16	$3\frac{1}{2}$	$4\frac{1}{2}$		$\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{1}{16}$	$\frac{15}{16}$	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	$1\frac{19}{32}$	$1\frac{7}{8}$
17, 18	$3\frac{1}{2}$	$4\frac{1}{2}$		$\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{1}{8}$	1	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	$1\frac{19}{32}$	$1\frac{7}{8}$
19, 20	$3\frac{1}{2}$	$4\frac{1}{2}$		$\frac{3}{8}$	$1\frac{5}{8}$	$1\frac{3}{8}$	2	$1\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{16}$	$1\frac{19}{32}$	$1\frac{7}{8}$

Taper of bored portion $\frac{1}{32}$ inch per inch of length.

Table of Dimensions of Flanges of Cast-iron Pipes, Valves, Etc.

Bore in Inches.	Flanges. Diameter.	Flanges. Thickness.	Diameter of Bolt-hole Circle.	Bolts. Diameter.	Bolts. No.	Weight of Bolts and Nuts per Joint, Lbs.	Diagrams showing positions of Bolt-holes, with reference to vertical line through centre of Bore.
2	$6\frac{1}{2}$	$\frac{9}{16}$	$4\frac{3}{4}$			2·02	Four holes.
$2\frac{1}{2}$	7	$\frac{5}{8}$	$5\frac{1}{2}$	$\frac{5}{8}$		2·07	
3	$7\frac{1}{2}$	$\frac{5}{8}$	6			2·07	
$3\frac{1}{2}$	8	$\frac{5}{8}$	$6\frac{3}{4}$			2·07	
4	$9\frac{1}{2}$	$\frac{3}{4}$	$7\frac{3}{4}$		4	3·52	
$4\frac{1}{2}$	10	$\frac{3}{4}$	$8\frac{1}{4}$	$\frac{3}{4}$		3·52	
5	$10\frac{1}{2}$	$\frac{7}{8}$	$8\frac{3}{4}$			3 66	
$5\frac{1}{2}$	11	$\frac{7}{8}$	$9\frac{1}{4}$			5·54	
6	12	$\frac{7}{8}$	10	$\frac{7}{8}$		5·54	
$6\frac{1}{2}$	13	$\frac{7}{8}$	11			5·54	
7	14	1	$11\frac{3}{4}$			12·15	Six holes.
$7\frac{1}{2}$	$14\frac{1}{2}$	1	$12\frac{1}{4}$			12·15	
8	15	1	$12\frac{3}{4}$			12·15	
$8\frac{1}{2}$	$15\frac{1}{2}$	1	$13\frac{1}{4}$			12·15	
9	$16\frac{1}{2}$	$1\frac{1}{16}$	$14\frac{1}{4}$	1		12·40	
$9\frac{1}{2}$	17	$1\frac{1}{16}$	15		6	12·40	
10	$17\frac{1}{2}$	$1\frac{1}{8}$	$15\frac{1}{2}$			12·63	
$10\frac{1}{2}$	18	$1\frac{1}{8}$	16			12·63	
11	19	$1\frac{3}{16}$	$16\frac{3}{4}$			12·81	
12	20	$1\frac{1}{4}$	$17\frac{3}{4}$			18·06	Eight holes.
13	21	$1\frac{1}{4}$	18	$1\frac{1}{8}$		18·06	
14	22	$1\frac{1}{4}$	$19\frac{3}{4}$			24·08	
15	23	$1\frac{1}{4}$	$20\frac{3}{4}$			24·08	
16	$24\frac{1}{2}$	$1\frac{5}{16}$	22			32·31	
17	$25\frac{1}{2}$	$1\frac{5}{16}$	23	$1\frac{1}{4}$	8	32·31	
18	$26\frac{1}{2}$	$1\frac{3}{8}$	24			32·68	
19	28	$1\frac{3}{8}$	25	$1\frac{3}{8}$		42·37	
20	29	$1\frac{3}{8}$	26			42·37	

Note (1).—The faced strips are to project $\frac{1}{8}$ inch from the faces of the flanges for all sizes, and their width is to be at least $\frac{5}{16}$ inch more than the thickness of the pipe.

Note (2).—Unless otherwise specified for any particular items, the lines regulating the positions of the bolt-holes are to fulfil the following conditions :—

(*a*). In valves and straight pipes with flanges at both ends they are to lie in the same vertical plane.

(*b*). In bends they are to be perpendicular to the plane containing the axis of the bore.

(*c*). In tees and branch pipes they are to be perpendicular to the plane containing the axes of the bores of the main and branch.

Specification of Flanged Sluice Valves.

1. The valves to be best double faced with four gun-metal faces, two on body of sluice and two on valve, gun-metal spindles and nuts, stuffing gland bushed with brass. The flanged ends to have faced strips and to be drilled for bolts, unless otherwise stated in the schedule. The flanges to be in accordance with the table of flanges (see above).

2. When flanged spigots and flanged sockets are ordered with the valves they are to be fitted to the valves, and each valve is to be completed with the necessary bolts and nuts for connection to the flanged spigots and flanged sockets. Bolts to be of sufficient length to show two threads clear of nuts when screwed up.

3. The valves will be tested, in the presence of the Superintendent, India Store Depôt, or his deputy, by hydraulic pressure to 260 lbs. per square inch.

4. After approval, the valves, flanged sockets, and flanged spigots are to be coated with Dr. Angus Smith's composition.

5. The keys entered in the schedule to be tee-handled, 3 feet long, fitted to heads of spindles, and japanned.

6. For shipment, each flange is to be protected by a disc of wood, not less than $1\frac{1}{4}$ inch thick, secured to the face by the bolts and nuts provided, or by other suitable means. Valves $2\frac{1}{2}$ inches and under to be packed in cases.

7. Each package to have stencilled on it in good oil paint the address, gross weight, and such shipping marks as the Superintendent, India Store Depôt, may require. Cases for keys or for the smaller valves to have stencilled on them in addition a description of their contents. Stencil plates to be provided by the contractor.

Specification of Wrought-iron Lap or Butt Welded Tubing and Fittings for the same.

All tubing for steam is to be lap welded and is to be tested to 600 *lbs. per square inch.*

All tubing for gas may be butt welded, and is to be tested to 100 *lbs. per square inch.*

Tubing above $1\frac{1}{4}$*-inch bore for water is to be lap welded, and is to be tested to* 300 *lbs. per square inch.*

Tubing not above $1\frac{1}{4}$*-inch bore for water may be butt welded, and is to be tested to* 300 *lbs. per square inch.*

1. The iron of which the tubes are made is to be soft, fibrous,

thoroughly well made, uniform in texture, and perfectly free from lamination, buckles, blisters, and all defects of manufacture. Samples cut from the tubes are to stand the following forge test, viz., bending close, when hot, through an angle of 180° without any sign of fracture (India Store Depôt Pattern No. 2845B).

2. As soon as possible after the receipt of the order, samples, 6 inches long, of the screwed tubes and sockets proposed to be supplied are to be forwarded to the India Store Depôt for approval, and the manufacture of bulk is not to be proceeded with till the Superintendent has approved these samples in writing.

3. Notice, in writing, is to be given to the Superintendent when the contractor is ready to have the tubes examined and tested at his works. All samples are to be forwarded to the India Store Depôt free of expense, and no charge is to be made for them.

4. The tubes and fittings are to be supplied of the lengths, numbers, and sizes detailed in the schedule, and of the external diameters and thicknesses detailed in the table (page 224), unless otherwise specified in the schedule. Each straight length, short piece or bend is to be provided with a socket at one end. The whole are to be screwed at both ends to the standard gas threads. In the case of long screws or connectors, one end of each socket and one side of each back-nut must be faced.

5. The whole of the tubes and fittings are to be tested at the contractor's works, in Great Britain, in the presence of the Superintendent of the India Store Depôt, or his deputy, by hydraulic pressure, to 600, 300, or 100 lbs. per square inch, according as they are required for steam, water or gas, and any which show any sign of failure will be rejected. The contractor is to provide the necessary apparatus, and carry out the testing at his own expense. The mark specified in the schedule is to be stamped on each length, socket or fitting approved.

6. After approval, the tubes and fittings are to be thoroughly cleansed from rust and dirt, and (*except those ordered "galvanized"*) coated :—

*(*a*). Outside with boiled linseed oil, which is to be allowed to dry before packing.

*(*b*). Inside and out with Dr. Angus Smith's composition.

7. After approval in the black, the tubes and fittings ordered "galvanized" are to be smoothly and evenly galvanized with the

* (*a*) or (*b*) to be struck out.

best Silesian zinc, containing not more than $2\frac{1}{2}$ per cent. of impurities. Samples of the zinc will be taken, if considered necessary, for analysis, and if found to be inferior to the above specification, the galvanized tubes, etc., will be rejected. The threads of galvanized tubes and fittings are to be cut after galvanizing.

Packing.

8. Straight tubes of not less than $1\frac{1}{2}$-inch internal diameter are to be sent loose. Those of less internal diameter are to be packed in bundles.

The threads of every tube, whether loose or in bundles, are to be protected at one end with the socket, and at the other with a wrought-iron ring. Any threads left exposed are to be protected with spun yarn soaked in linseed oil securely wrapped round them and tied on.

9. The bends and fittings are to be carefully packed in cases.

Marking.

10. All bundles and 10 per cent. of the tubes sent loose are to have the address and such shipping marks as may be required by the Superintendent, India Store Depôt, stencilled on them in good oil paint. The contractor is to provide the necessary stencil plates.

Wrought-iron Tubes.

Table Showing External Diameters and Thicknesses of Tubes, and Dimensions of Flanges.

Nominal Bore—*variable.*	External Diameter—*constant.*	Threads per Inch.	Thickness.						Diameter of Flanges		
			For Gas.		For Water.		For Steam.		Diameter n Inches of		
			S.W.G.	Inches.	S.W.G.	Inches.	S.W.G.	Inches.	Flange	Bolt-hole Circle.	Bolts.
ches	Inches.										
$\frac{1}{2}$	0·8257	14	12	·104	11	·116	10	·128	$3\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{8}$
$\frac{3}{4}$	1·041	14	11	·116	10	·128	9	·144	$3\frac{3}{4}$	$2\frac{3}{4}$	$\frac{3}{8}$
1	1·309	11	10	·128	9	·144	8	·160	$4\frac{1}{2}$	$3\frac{1}{4}$	$\frac{7}{16}$
$1\frac{1}{4}$	1·650	11	9	·144	8	·160	7	·176	5	$3\frac{5}{8}$	$\frac{1}{2}$
$1\frac{1}{2}$	1·8825	11	8	·160	7	·176	6	·192	$5\frac{1}{2}$	$4\frac{1}{8}$	$\frac{1}{2}$
$1\frac{3}{4}$	2·047	11	8	·160	7	·176	6	·192	$5\frac{3}{4}$	$4\frac{3}{8}$	$\frac{1}{2}$
2	2·347	11	8	·160	7	·176	6	·192	$6\frac{1}{2}$	$4\frac{3}{4}$	$\frac{5}{8}$
$2\frac{1}{4}$	2·5875	11	7	·176	6	·192	5	·212	7	$5\frac{1}{2}$	$\frac{5}{8}$
$2\frac{1}{2}$	3·0013	11	7	·176	6	·192	5	·212			
$2\frac{3}{4}$	3·247	11	7	·176	6	·192	5	·212	8	6	$\frac{5}{8}$
3	3·485	11	7	·176	6	·192	5	·212			
$3\frac{1}{2}$	3·912	11	7	·176	6	·192	5	·212	$8\frac{1}{2}$	$6\frac{3}{4}$	$\frac{5}{8}$
4	4·339	11	7	·176	6	·192	5	·212	$9\frac{1}{2}$	$7\frac{3}{4}$	$\frac{3}{4}$

Note (1).—The actual bores of these tubes vary with the purpose—gas, water or steam—for which they are required. The external diameters are constant, so that all may be screwed to the standard gas thread.

Note (2).—All flanges for tubes of the above sizes have four bolt-holes, which are to be drilled unless the flanges are ordered "blind." When bolts and nuts are ordered for flanged joints, the bolts are to be long enough to show two threads clear of the nuts when screwed up.