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CONTENTS.

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THE SIEGE OF MALTA,
1940-1942.

By LIEUT.-GENERAL SIR WILLIAM G. S. DOBBIE, G.C.M.G., K.C.B., D.S.O.,
Colonel Commandant, R.E.

MUCH has been said and written on the subject of the defence of Malta in recent months, and that is not surprising in view of the great interest aroused in England and indeed, throughout the Empire, about the happenings in that small outpost of Empire. It is possible that this interest was enhanced by the unfortunate happenings in other parts of the world where we were suffering reverses and disasters of the first magnitude—and all the more disquieting because they were so unexpected. In fact, for a period, Malta was one of the very few bright spots on our strategic horizon, a condition which was enhanced when our forces in Egypt were driven back to the gates of Alexandria. It was then, especially, that Malta's continued integrity became so vitally and obviously important. It was our last precarious hold on the Centre Mediterranean. Its loss would have not only impaired our offensive plans for the future, but would have gravely compromised our defence of Egypt in the present. As a fact, its retention by us in those dark days of last summer did make a real and invaluable contribution both to the defence of Egypt and then to our great counter-offensive. It is, therefore, quite understandable that the imagination and interest in Malta of the British peoples have been so greatly stirred. That is my excuse for adding to what has already been said and written, beside the fact that some useful lessons may even now be drawn from what has happened there.

It is not necessary to say much about the strategic importance of Malta. That has always been well understood, though it is possible it is now better understood than ever, since the lesson has been so pointedly forced home upon us by the hard force of circumstances. Now the man in the street has a fairly clear perception of its importance, even if in times past he paid but little attention to it. Suffice it to say that whereas Malta always was of importance as a base, even when our circumstances in the Mediterranean were comfortable, it suddenly became vital when the whole strategic situation changed overnight in the late spring of 1940, when France dropped out of the war, and Italy came in against us. Then it was that it was more needed than ever, and then it was that its security was most seriously menaced. However, a fortress is intended to prove its worth in days of adversity, when the local military situation is unfavourable. To that end it is usual to provide adequate means to enable it to resist any attack that is likely to be made on it, by the provision of a sufficient garrison, and of the necessary equipment and munitions of war. In the case of Malta, that provision had not been made. It had not been found possible to do so. The change in the strategic situation to which I have referred was so sudden that there was no time to make the necessary dispositions then. Further, the resources of the British Empire were at that time stretched almost to breaking point. We stood alone, and we just had not enough men or material to meet our needs and go round. Many important places, of which Malta was one, had to go without for this reason. Malta was just one of many proofs of our lack of preparedness which reach back into the pre-war days. In those days we used our limited resources in the way which seemed wisest then. Malaya was much higher on the priority list than Malta—and who is to say that that choice was not right, even in view of the subsequent happenings ? But for one reason or another

Malta's defensive resources were terribly meagre when Italy stabbed France in the back and entered the war on the side of Germany.

It must, of course, be understood that Malta's *raison d'être* was, and is, and always will be, offensive rather than defensive. Its very geographical position makes that clear. It is but 60 miles from Sicily and 1,000 miles from the nearest British territory, and is directly on the life line on which the Italian forces in Libya depended for their very existence. So long as we hold Malta, and are able to operate from it against that life line we can exercise a very far-reaching influence on the course of any operations in North Africa—especially those that might affect the security of Egypt. That is common knowledge now, and it is already sufficiently evident that the forces based on Malta did in fact exercise a very great, perhaps decisive, influence on the operations in Libya and Egypt. When we were holding on desperately at El Alamein, who can say how far the final glorious outcome was due to these Malta forces? The enemy recognized this fact, as is witnessed by his tremendous efforts to neutralize the base and abate the nuisance. But Malta's offensive potentialities are not confined to such activities. Its proximity to Italy and Sicily make it an ever potential threat to the Fascist Regime, a fact which is not overlooked by Mussolini and his advisers, and which no doubt is viewed with some concern. It is possible that the future course of events will justify their uneasiness.

But in order that a base may be used for offensive purposes, it must be protected from interference, and defended against attack. It was in this respect that our resources were so woefully meagre. In those early days they were entirely inadequate, and the enemy knew it. It does not matter saying this now, since things are very different to-day. Malta is now very strong, as the enemy will quickly find to his cost should he attempt to capture the Fortress. But in the summer of 1940, the situation was definitely disquieting, and it was not possible, however much one would have wished it, to effect any immediate remedy—since it was then even more vitally important to make our position at home reasonably secure and our resources had to be devoted to that end. The situation was recognized and accepted by Malta as well as by other places, and all that could be done was to put a bold face on things and make the best of them.

The problem of the defence of Malta really was a double one, though the two parts reacted on each other and dovetailed into each other. Each part was vital. Failure in either would have spelt disaster. The two parts of the defence problem were as follows:—

(*a*) Defence against attack in a military sense: i.e., an attack by sea or air or both with a view to overrunning, capturing and occupying the Island.

(*b*) Defence against shortage of essential supplies, or in other words defence against the reduction of the fortress by starvation. A brief consideration of these two parts of the problem may be of interest and value.

I have pointed out that the defensive resources at the time when Italy became our active enemy were grossly inadequate. The following particulars will illustrate this statement.

(*a*) No aircraft could be then allotted for the defence of the Fortress.

(*b*) The anti-aircraft defences of the Naval Base and aerodromes were very meagre.

(*c*) Apart from one Maltese Territorial Battalion which at that time was inexperienced and incomplete, the infantry garrison was equally meagre.

(*d*) The protection of vital installations was, with some few exceptions, in a very backward state. In all these, and many other respects, things are very different now—but the above gives the situation obtaining at the time in question.

As regards the lack of aircraft, that was no doubt due to the impossibility of sparing any then for Malta. But it must be remembered that many persons, not confined to the ranks of our enemies, thought that it would be impossible to operate aircraft from the few airfields in Malta, in view of the proximity and overwhelming strength of the Italian Air Force. The event has shown that those persons were mistaken—and the incorrectness of this opinion is enhanced by the fact that even when the Italian Air Force was reinforced by an exceedingly strong force of the *Luftwaffe*, our aircraft continued to operate from Malta in spite of the prodigious efforts of the enemy to stop them. All credit is due to the A.O.C. and his subordinate officers who saw the falsity of the idea, and determined whatever it cost to demonstrate to all the world that where there is a will there is a way, and that aircraft could operate even in the very adverse conditions prevailing. When war with Italy loomed darkly on the horizon the A.O.C., Air Commodore (now Air Vice-Marshal) Maynard, was not content to leave the sky over Malta entirely undisputed. He " found " four fighter aircraft in cases in the naval stores. These had been earmarked as reserves for the Fleet Air Arm, but the A.O.C. acquired them, presumably by consent, fitted them up, and set to work to train some of his officers to fly and fight them. This foresight and initiative on his part, were worth a great deal when the attacks on Malta began, and undoubtedly helped to keep within measurable bounds the efforts of the enemy. All credit is due to the young pilots of these four aircraft who cheerfully accepted tremendous odds, and by their courage and skill affected and to some extent upset the plans of the enemy. Through the hazards of war and other causes the four Gladiators were gradually reduced in numbers—but they formed the beginning of a fighter force which has ever since those dark days been present at Malta in varying strength up to the present day when it is extremely formidable. So much for the fighters. As regards bombers, in spite of the offensive role of the Fortress of Malta, we started the war with Italy with no bomber aircraft with which to carry out our primary task of attacking the enemy's communications. They came later, in ever-increasing strength, but at first there was none.

The lack of an adequate fighter force at Malta was not offset by a strong force of anti-aircraft guns. Rather the reverse. The fighter weakness, of course, threw a greater burden on to the guns, and it was, therefore, doubly unfortunate that they were at this vital period totally inadequate in numbers. There again, we had to make the best of what we had got, and use our limited resources to the best possible advantage. Apart from that, all we could do was to decide exactly where to put fresh guns when they arrived and to make every preparation for their installation.

So much for air defence. Enough has been said to show how entirely inadequate it was in those early days of the war, when a full scale attack on the Fortress appeared likely if not inevitable. When this full scale attack did not materialize and the enemy contented himself with the easier task, as they thought, of bombing the island into submission, the air defences both of the Army and R.A.F. buckled to, and performed wonders. It is not that the evident material casualties inflicted on the enemy were very great, but the effect of the guns and fighters between them certainly discouraged the enemy sufficiently to give considerable relief to the Fortress, its garrison and people. It is true that it does not take much to discourage some of our enemies, but the achievement of the two services was none the less praiseworthy, and reflected great credit on all concerned. The activities of these forces of ours may have been the cause of an official Italian *communiqué* issued not long after they had entered the war. It stated : " We have destroyed all military objectives in Malta." They further stated in more detail that they had destroyed the coal mine and the railway! Perhaps the wish was father to the thought. Perhaps they considered that it provided an adequate excuse for not pressing their attacks on a target which was less defenceless than they had imagined. Whatever the reason, we had no cause to complain on that account, especially as the reference to the coal mine which has never existed, and the railway which ceased to exist many years ago, caused much amusement to the garrison and people.

The weakness of the infantry strength was also a matter of considerable concern. The Maltese territorial battalion was, as I have said, inexperienced then, and it was also in the process of throwing off other battalions—a process which imposed a tremendous drain on its resources, and was bound for the time being gravely to affect its effectiveness. Later on it became an extremely good unit, but at the time in question it was very seriously handicapped. But whether 4 or 5 battalions, the infantry force was entirely inadequate to discharge the duties which might be imposed on it. It had to be prepared to resist seaborne invasion on the extensive coastline where a landing was practicable. It had to deal with airborne invasion probably at the same time. It had to deal with attempts to sabotage aerodromes or other vital installations. It had to be prepared to perform any of the other duties which might fall to the lot of infantry in a fortress in wartime, such as assisting the civil power to control the population. All these tasks might well have had to be faced at one and the same time, and four or five battalions were obviously and ludicrously inadequate. But it is all we had, and all that could be spared at the time. The danger was realized, accepted and faced by all concerned.

It is therefore clear that the state of our defences when Italy went to war was such as to invite attack. It was certainly a reasonable thing to expect when one realized that our weakness must have been known to the enemy. The expectation was also fortified by the attitude of the Italians themselves. Both before they entered the war and for some time afterwards they were boasting loudly and confidently that they would overrun Malta in a few days. These boasts, coupled with our known weakness, would have justified us in expecting them to make some sort of attempt to capture Malta. They must have known the importance to them of the elimination of Malta, and that its continued possession by the British would inevitably be a continued menace to their well-being. Why then did they not attack it? Others of our enemies would assuredly have made the attempt. Why did not the Italians do so? It is difficult to say. Perhaps the bold face shown by the garrison and people of Malta was a disquieting factor. Perhaps they thought we must be stronger than they had imagined. Perhaps they were somewhat distrustful of their powers to pull off a successful combined operation against opposition. Perhaps they thought they could achieve the same result by easier methods, and that by the short cut of bombing attacks to reach the desired goal. Which of these reasons was the correct one, it is impossible to say—but I am inclined to think that all the reasons given may have contributed to their decision, and that the one last named may have been the most powerful one of all. If so, they fell into the mistake into which others have fallen before, and fondly imagined that success in war can be won by short cuts. It is a fallacy favoured by the ostrich mentality, being a refusal to face unpleasant facts, and deliberately choosing to live in a fool's paradise. Moreover, if that is the explanation of their unwillingness to assault the fortress it shows a grievous miscalculation. Presumably they thought that the bombing of the densely populated island of Malta would break the spirit of its people, and compel its surrender. Although the very close neighbours of the Maltese people, little did they apparently know them or the stuff of which they were made. Perhaps they judged them by their own standards, fondly imagining that hard knocks would soon bring them to their knees. But the Maltese is made of sterner stuff than that, a fact which the Italian, and, indeed, the German too, has had to learn to his cost. No more serious miscalculation could have been made. It was fundamental and vital. Through it (if our surmise is correct) they abstained from assaulting the fortress at a time when conditions were very much in their favour. That opportunity (if it existed) has gone, and gone for good. With it perhaps also went their chance of a victorious Mediterranean policy with all the far-reaching implications of such a development. All that being so, it is truly remarkable that they never made the attempt to implement their boastful utterances. Of course, their attempt might have, probably would have, ended in failure. But still one cannot help feeling that they should have made the effort. The weakness of the defences was thus very pronounced in the early days. But as soon as it was possible to send them, reinforcements and equipments began to arrive, and gradually the strength of the defence has been built up, until now it has become so formidable that the stoutest hearted enemy may well be excused if he hesitates to try conclusions with it. That part of the problem of defence has thus been faced and we hope passed. We will now turn to the other part of the problem which confronted those concerned with the security of Malta—that is, the problem of supply.

In order to understand this part of the problem rightly it is necessary to have a correct background. One of the chief factors affecting this problem is the size and density of the population of Malta. Malta is a small country—only 100 square miles in extent, but it carries a population of no less than 270,000 persons, giving a density of 2,700 per square mile. This is a stupendous figure, and is in fact the highest figure for any country in the world of an equal or greater size. Moreover such a density makes it quite impossible for the country to produce more than a mere fraction of its requirements of food. Most of the food required and all other needs have to be brought in by sea from outside. It is therefore very obvious what an extremely serious problem, in the matter of supplies, the size of the civil population imposed on the fortress. It was not enough to safeguard the island from assault. It had also to be safeguarded from starvation, which might in certain circumstances constitute an even more difficult problem. After the defection of France, food had to be brought either from Gibraltar or Egypt. In the former case the ships bringing it had to pass through the Sicilian narrows between Sicily and Tunis, guarded by the island fortress of Pantalleria. In the latter case the problem was easier so long as the enemy was not in Greece and Crete. But when these were lost, and especially when Cyrenaica and a large part of the north coast of Egypt were in enemy hands, the problem of supplying Malta became one of the greatest difficulty. Thanks to the devotion of the Royal Navy and the Merchant Navy, these difficulties were faced and overcome, though in so doing a grievous price had often to be paid. But the importance of supplying Malta, not only with the means of existence but with the stores required for its offensive role, was so vital, that the price exacted was willingly paid by those gallant men, who forced their way through enemy opposition and delivered the vital stores to the fortress.

The difficulties which the Royal Navy had to face in order to replenish Malta's larder were recognized by the people of Malta as well as by the government with sympathy and concern. The policy adopted was therefore to reduce by all means possible the calls on the Navy. This involved a close and very strict control of foodstuffs and all materials in the Island, so as to ensure that the supplies should be made to last as long as was possible. To this end the people and the garrison accepted really " short commons," and accepted them willingly. They learnt to do without to an extent seldom contemplated. The amenities of life were ruthlessly cut, and many hardships were perforce imposed. Moreover, the question of supplies of all sorts was co-ordinated between the three fighting services and the civil population. The supply problem was regarded as one problem and not four. All the small details as well as the larger principles were considered, examined, and decided on together by representatives of the four authorities concerned working in real co-operation with each other. All these measures undoubtedly made a very real difference and enabled Malta to eke out its supplies to the limit, and thereby reduce the demand for shipping and Naval intervention. Malta has now been restocked, and it is hoped that, please

God, her difficulties in the future will be less than in the past. But the garrison and people of Malta can look back on the past two and a half years with some satisfaction and pride, as they realize that the hardship and privations which they willingly accepted did in fact make a real contribution to the safety of the fortress and its continued usefulness.

Bound up with the question of supplies was that of the general well-being of the people. A population of the size of Malta's in the confined area of a fortress is no light commitment. It provides serious problems of all sorts, problems which had to be faced and solved along with the other problems of a more definite military character. The well-being of the people was obviously a very definite factor in the defence of the fortress. The embarrassments and difficulties which would have arisen from the neglect of the people's interests would undoubtedly have prejudiced the defence of the fortress. It was, therefore, necessary to pay much attention to this side of the defence problem. In order that it, as well as the Service problems, should be considered as one problem, the Defence Committee consisted of the heads of the three fighting services and the Lieut.-Governor representing the civil side, all under the Chairmanship of the Governor. This committee considered all policies and matters of principle, and details were thrashed out by a similar committee consisting of Chiefs of Staff and the Assistant to the Lieut.-Governor. It was clearly recognized by all in responsible positions that the problem of the defence of Malta was one problem and was not a combination of sectional problems. All interests in Malta stood or fell together—and the committees above-mentioned helped to ensure that this theory was translated into fact in the most practical way. A slogan aptly described the attitude of the committee. "Malta stands on four legs—the Navy, the Army, the Air Force, and the Civil population." The co-operation and understanding between these four "legs" was undoubtedly of a high order, and contributed in no small measure to the successful defence of the fortress.

Among the many matters which had to be co-ordinated was the distribution of labour and building materials. There was never enough of these to meet all the requirements of the various authorities, and it was, therefore, necessary to consider these requirements all together, and to decide on a certain priority. This was done by a sub-committee on which the Chief Engineer was the representative of the Army, and his "opposite numbers" of the other two services and Civil Government. The interests involved were often conflicting, but it was usually found possible to reach an agreed decision. When that could not be done, the matter could be referred to the Defence Committee for final solution and decision.

Such, in the main, were the defence problems of Malta. There were, of course, innumerable subsidiary problems which afforded plenty of scope for those who had to deal with them, and all who held responsible positions had plenty to interest them and occupy their minds. I consider it to be a great privilege to have been associated with the fortress and the people of Malta during those two memorable years, 1940-42, and that is also, I am sure, the feeling of others. It was something to see a simple people enduring hardship uncomplainingly. It was something also to face difficulties with others, and by mutual understanding and real co-operation to overcome them.

It has already been pointed out that Malta's main function is offence. To this end Naval and Air Forces were and are based on Malta, and from it attack the enemy's communications between Italy and Libya. These attacks were carried out by one or other of the two services working independently or by both working together, and they have in the last two years been remarkably successful. The toll which has been taken in this way from Axis shipping has been extremely heavy—and it was for this reason that both in the winter of 1940-41, and again since December 1941, the Germans have come to the aid of their Italian allies in a supreme effort to neutralize the fortress and stop its offensive activities.

These interventions on the part of the *Luftwaffe* were no light thing. The force detached to Sicily and maintained there was a very large one, and consisted of first-class units. Its maintenance against the heavy losses incurred (and they were very heavy) must have imposed a very severe drain on the German resources, and caused a most unwelcome detachment of squadrons which they badly needed elsewhere. This has been especially the case since December, 1941. The German Air Forces, with some assistance from the Italians, have for months made the most determined and sustained attacks against the harbours and airfields of Malta. The strength and persistence of these attacks and their readiness to accept almost prohibitive losses are the measure of the importance in which they held the elimination of the Malta offensive. That in itself is a source of satisfaction to us, as is also the knowledge that in spite of all the enemy could do our activities, though from time to time reduced or weakened, were never stopped. To-day they are as vigorous and as effective as ever.

In the period up to May, 1942, our air defences were handicapped by a shortage of fighter aircraft. It was a period in which the heaviest and most persistent attacks were experienced, and consequently an unprecedented burden was placed on the A.A. guns. These rose nobly to the occasion and produced truly remarkable results. No doubt the amount of practice they had day after day against "live" targets improved the technique of the detachments, until the A.A. Artillery in Malta reached a standard probably never attained before. In one month the guns of Malta alone destroyed for certain over 100 enemy aircraft. The fighter aircraft also did prodigies, fighting incessantly against great odds, and taking a heavy toll from the enemy. Malta certainly was the graveyard of many Axis aircraft, and this was especially the case in the first six months of 1942, a period when the enemy's air resources were greatly taxed everywhere. We are now (January, 1943) seeing something of the result of that excessive strain imposed on the enemy, and it is not unreasonable to suppose that the "Battle of Malta" has made a real contribution to the advantages and successes we are now enjoying.

Much has been said, especially before the war, of the great efforts made by Italy to alienate the sympathies and the loyalty of the people of Malta from the British Empire and to bring about a re-orientation of their outlook towards Italy. The Italians were well placed, both geographically and economically, to exercise much pressure and disseminate insidious propaganda. They certainly worked hard to that end and were by no means scrupulous as to their methods. In such circumstances it would have been remarkable if some seed had not fallen on good ground, and if some persons in Malta had not become infected with the poison. But the truly remarkable thing is how few were so affected. Out of the 270,000 persons in Malta, only an infinitesimal number were so tainted. Their loyalty to Britain did not waver. I have pointed out already how grievously the Italians miscalculated when they thought that their bombs would break the spirit of the people of Malta. They also miscalculated in the effect of their propaganda, in spite of all the advantageous circumstances in which it was launched. It largely fell on deaf ears—and any who were hovering between two opinions and were toying with the pernicious ideas were suddenly cured once and for all by the detonation of Italian bombs. Those who were too deeply affected by the virus were speedily locked up—and later deported. But their numbers were extremely small.

In the foregoing remarks I have endeavoured to give a general preface of the problems which faced the Governor and the government of Malta. I have not attempted to go into detail—nor have I dealt with the many and most interesting purely military and technical problems which arose constantly. I have purposely omitted any consideration of the Engineer problems of the fortress. These were as important, as complex and as numerous as one would expect them to be, and are productive of the most valuable lessons. I hope these will be adequately dealt with by an officer who was more directly and closely associated with them than I was. There is much which can and should be written on this important subject.

Before bringing this paper to a conclusion, one other thing should be said. Many of us in Malta realized how much we needed Divine help to enable us to carry out our task. We asked for that help—and we have no doubt that it was given, and that God's good hand protected Malta. I cannot but acknowledge that humbly and thankfully, and I know that there are others who do the same. I firmly believe that that Divine help was the chief reason of the successful defence of Malta.

In conclusion it may be desirable to attempt to define some of the lessons of a more general character which have been learnt, or should have been learnt. To my mind they include the following :

(*a*) Difficulties, however great, if faced with a stout heart (as was done by the people and garrison of Malta) can be overcome.

(*b*) Difficulties shared and faced together in the true spirit of co-operation (and not only the letter) are robbed of much of their sting.

(*c*) Reliance on Almighty God is just as real and practical a thing to-day as it ever has been in the past.

EMERGENCY MOBILE WATER SUPPLY PLANT.

By LIEUT.-COLONEL J. D. K. RESTLER, O.B.E., M.INST.C.E.

IT is a curious fact that very few people appear to appreciate that in the event of the destruction of the pumping machinery of a city or town which is dependent upon a pumped supply of water then that city or town would have to be evacuated in about 48 hours, and this might mean the movement of several million people at short notice. It is also not appreciated that even the large cities or towns usually have only a very few pumping stations of primary importance which, if destroyed, would cripple the supply. There may be a number of subsidiary stations of minor importance used for supplying small areas, but these would be of little use in the event of the main stations being put out of action.

During the latter part of the last war the writer had exceptional opportunities for studying the effect of bomb damage on water supply installations, particularly in the London and surrounding areas, but although the damage was serious on one or two occasions none of the key pumping stations received direct hits, although on numerous occasions the supply was affected from the fire-fighting point of view. During this period it was realized that bombing might have a crippling effect on cities and towns and with this realization it followed that an entirely new problem had to be studied and every effort made to find a satisfactory solution.

A very mistaken line of thought existed before the last war which assumed that a city or town could continue to be occupied by the application of a severely rationed water supply, but the people who had put this idea forward had not clearly understood the many problems associated with a modern water undertaking, and therefore a sense of false security had grown up. It had been said that the population could still occupy a city or town if two gallons of water per head per day were available. This statement was made by people possessing limited technical knowledge and therefore unable to appreciate that, with the lay-out of a modern water undertaking, it was, in fact, completely impossible to control the quantity of water supplied to individuals. That is to say that so long as the mains were charged with water, thus supplying the service pipes, it was impossible to prevent individuals drawing water from their taps.

Suggestions were made that service mains could be shut down, with the result that many areas would not have pipe supplies of water and, in fact, all water used in these areas would either have to be carted or carried to the districts concerned. It will be readily seen that if any such suggestions were put into operation, it would be quickly followed by an outbreak of typhoid fever and other diseases, as the whole of the sewerage system would cease to operate. This, in fact, did actually happen about the middle of the last century when large parts of London were supplied on what was known as the intermittent system, but obviously the effect would be much more serious in a city or town which had been built up on modern lines and this would be greatly aggravated owing to the fact that in most cases the population of a given area is now very much greater than was the case in the latter part of the last century, owing to the building of very large blocks of flats, etc., containing a great number of people in each building.

Origin of Emergency Plant Scheme.

Immediately after the last war the writer began to study the two main questions which would require solution if a reasonable degree of safety was to be provided in connection with the water supply, having regard to the lesson learned during the air raids. These two questions were :—

(1) The rapid restoration, in a temporary manner, of the output of pumping stations if they were destroyed.

(2) The rapid repair of trunk and distribution mains after streets had been heavily bombed.

The question of designing and building large portable pumping units, each capable of delivering several million gallons per 24 hours against high pressures appeared to be an almost impossible task and received severe criticism when it was suggested that this could be done.

By 1926 a scheme was sufficiently far developed to allow drawings to be made showing plants capable of delivering water up to 8 million gallons per 24 hours against a pressure of 150 lbs. per square inch. These plants could be conveyed along ordinary roads and put to work at short notice, as arrangements were made for the delivery and suction pipes to be sub-divided in such a way as to allow of a number of small pipes being used which could be connected to the permanent mains at points beyond those destroyed.

Although it was recommended that experimental plant along these lines should be built the recommendation was not accepted as, at that time, it was difficult to make people believe either that war would again occur in the following fifty years or that the water supply was likely to be damaged. The writer did however, continue to develop the scheme and introduced modifications and improvements from time to time embodying the latest practice.

About 1932, owing to the satisfactory developments which were taking place in connection with submersible deep well pumps, a scheme was prepared for making use of this type of machinery which was also to be portable, easily transported and quickly put to work.

Trunk and Distribution Mains.

The streets of many cities frequently have a number of large mains under their surface and these mains are frequently worked at different pressures, so that in the event of several bomb craters being made along the line of a street, the whole of the mains in that street might be blown out at several points and where buildings collapse into the street the dividing valves and cross-connections might be covered with many feet of rubble. The problem was to devise some scheme whereby a quick connection could be made to the ends of the undamaged portions of the mains and some form of flexible connections made between the two ends, and where necessary the higher pressure mains could be supplied with water from the low pressure mains by the introduction of suitable pumping plant in the streets.

The outline of the scheme was laid out so as to produce an emergency service which would provide at suitable points all the plant, apparatus and material required for carrying out without delay the whole of the emergency repair work, together with the necessary administrative services, such as emergency communications and emergency staff for the administration of the temporary work.

By 1936 it had become obvious that there was a serious possibility of war breaking out in the comparatively near future. The writer prepared the necessary drawings and specifications for suitable emergency plant embodying the latest modern practice and authority was given for the plant to be manufactured.

Design and Supply of Emergency Machinery.

It was decided to provide two types of plant :—

(1) A deep well pumping plant capable of drawing water from a depth of about 300 feet which would deliver water into mains at 150 lbs. pressure and have a capacity of 1½ million gallons per 24 hours ;

(2) A surface pumping plant capable of delivering water at the rate of 8 million gallons per 24 hours at a pressure of 120 lbs. per square inch.

Each unit to be self-contained and capable of travelling along ordinary roads at 20 miles per hour and able to be put to work within a few hours of its arrival at the scene of the accident.

(a) Deep Well Pump.

Careful consideration was given to the question of the most suitable type of deep well pump to be used for emergency plant of this description. The principal requirements which had to be met was that the pump should be self-contained, light and of sufficiently robust construction to ensure that it would not be damaged by rough handling when being erected on a site which had been severely damaged by a bomb and possibly was still being bombed when the work of erection was proceeding. In order to meet these requirements it was clear that neither of the orthodox types of deep well pumps was suitable—that is to say, reciprocating type or vertical spindle rotary—driven from overhead gear.

For some time, pumps of the submersible type—that is to say, centrifugal pumps directly connected to alternating current motors—had been successfully used for comparatively low heads, but steady progress had been made in the development of pumps of this type to make them capable of delivery against high pressures, and being so arranged to pass the whole of the water pumped through the windings of the motors. On account of this satisfactory progress it was decided to make use of this type of pump for the deep well purpose, and also for pressure-increasing purpose at the point where the deep well water delivered to the surface was to be pumped into the mains. By this arrangement no lining-up or careful fitting work was required, as the pump and motor were self-contained and the whole piece of apparatus was only about 9 or 10 feet long and 18 inches in diameter. Provision was made for the pump to be lowered down the boring and supported by the rising main, the three-phase cables being clipped on to the rising main at suitable points.

The decision to use a pump of the submersible type having been taken, it was necessary to provide for the installation of suitable portable generating plant, and this introduced a number of special problems such as the type of prime mover to be used and a number of other points.

(b) Boiler.

It was further appreciated that it was very desirable that the plant should be capable of using any form of fuel—that is to say, coal, oil, wood or debris from destroyed buildings or streets, and it was therefore at once apparent that only steam plant would meet this requirement.

This fact immediately brought to notice the point that no existing plant would be suitable and therefore a special design would have to be produced. Firstly, there was no boiler available which was suitable for generating the comparatively large amount of steam required and which at the same time was sufficiently light to allow it to be transported at considerable speed along ordinary roads, bearing in mind the limitations in width and height due to traffic requirements, bridge clearances, etc.

As soon as the principal dimensions of suitable plant were roughed out, it was found that the boiler would be required to generate between 5,000–6,000 lbs. of steam per hour at between 180–200 lbs. pressure per square inch, and a small amount of superheat was also desired. It will be seen that these requirements necessarily led to the project being very carefully examined, as there was little useful information available concerning a plant with these limitations. It was finally found that a water-tube boiler, either of the single drum and field tube type or of the two drum type, was most suitable. One of the great difficulties which had to be overcome was to provide a sufficient fire-grate area which could be fitted into the width available, having regard to the limitations of traffic requirements, and also to keep the length of the grate short enough to be hand-fired. It will be clear that many obstacles had to be overcome before such a fire-box arrangement was produced, and there were other difficulties which had to be eliminated before suitable draught control was obtained. One of the requirements which had to be met was that the boiler must be capable of raising steam from cold water to full pressure within 45 minutes from the time the fire was lit. It was also necessary to ensure that the centre of gravity should be sufficiently low to allow the lorry upon which the boiler was mounted to remain stable when travelling along ordinary roads at a reasonably high speed, and in addition to the main boiler, the lorry also had to carry the main feed pump and main feed tank.

It having been decided to use a boiler of the water-tube type, it was an obvious essential that all the steam used by the plant should be condensed and returned to the boiler in order to ensure that as small a quantity of make-up feed as possible should be used, thus preventing corrosion or scale taking place in the tubes. It was also necessary that as little steam as possible should be discharged into the atmosphere round the plant, since the whole apparatus might have to be put to work in streets still carrying traffic, and on this account it was also desirable to reduce noise to the absolute minimum. With these points in mind provision was therefore made for the exhaust from the feed pump to be taken through a coil in the main feed tank, which not only condensed the steam from the pump but also retained a considerable portion of the heat left in the exhaust steam.

(c) Prime Mover.

In view of the previous decisions the choice of prime mover became very limited and it was finally decided to use plant of the turbo-alternator type. This consisted of a small turbine driving an alternator and its excitor through a suitable speed-reducing gear box. The turbine was arranged to exhaust to atmosphere for starting purposes, but it was also arranged to exhaust into a surface condenser which would be supplied with its circulating water from the main pump delivery, thus providing that when the plant was first being started up, the apparatus would exhaust to atmosphere, but as soon as water was being delivered by the main pump the whole of this water would be taken through the condenser casing. The condenser was placed immediately below the turbine and the condensate was discharged from the condenser into a small hot well placed below the condenser itself.

In order to keep the whole plant as simple as possible, provision was made to use the condenser to condense the steam only and not to form a vacuum, and no extraction pump or air ejectors were therefore required, the whole function of the condenser being to condense the steam and so save the distilled water for the boiler.

When the plant was required to be put to work, the trailer carrying the boiler was to be brought up close to the trailer carrying the turbo-alternator. The main steam pipe from the boiler to the turbine was to be of the metallic flexible type, and the water from the hot well on the turbo-alternator trailer was to be delivered by means of a steam ejector to the feed tank on the boiler trailer through a rubber flexible hose. These connections were the only two required to be put together in order to put the plant to work.

The general arrangement of the whole plant is therefore as follows :—

(*a*) A submersible pump complete with its rising main to be lowered down the boring by means of a set of shear legs :

(*b*) A portable alternator capable of generating three-phase current, 400 volts, 50 cycles :

(*c*) Hand-fired boiler to provide the steam required for the turbine :

(*d*) A submersible pump to be used in a horizontal position and which would sufficiently raise the pressure of the delivery from the deep well pump to allow water to be pumped into the mains.

It has already been explained that the whole of the water delivered from the deep well pump had to pass through the condenser on its way to the horizontal pressure pump.

Owing to the unorthodox design of this plant, it was found that many details required special attention during manufacture, but when the whole plant was delivered and put to work, no major alterations were required. It has been satisfactorily used on many occasions—the most noteworthy being when a serious accident occurred at a pumping station situated some 35 miles distant from the point where the plant was normally stored. On this occasion the plant was despatched, erected and put into commission within a period of 11 hours including travelling time. The portable shear legs and other tackle which normally accompanied the unit were used, and the whole of the work was carried out by four men.

UNITS OF 8 MILLION GALLON CAPACITY.

The main principles governing the design of these units remain the same as those governing the small units, in that they must be capable of travelling at fairly high speeds along ordinary roads, able to use any form of fuel, and having only a few loose pieces to be connected up when the plant was being put to work.

It was finally found that the most suitable arrangement was to use a water-tube boiler of larger capacity but of the same general design as the smaller plant and to use a steam turbine and surface condenser as the prime mover, but in this case, in order to produce the power required, the condenser was arranged to give a high vacuum in addition to condensing the steam. This meant the introduction of air ejectors and an extraction pump, the steam turbine being connected through a gear box to a single or multi-stage centrifugal pump.

From an operational point of view it was found that, in order to deal with the comparatively large quantity of 8 million gallons of water per 24 hours, it was necessary to sub-divide the suction main into two or four 9-inch flexible connections according to the distance through which it was desired to draw the water. On the delivery side a manifold pipe was bolted on to the delivery from the pump. Connected to this manifold were 24 2½-inch standard fire brigade screwed-down valves, to which 24 lines of standard rubber-lined hose were connected, these lines of hose being laid along the ground to the point where the water was to be delivered into the undamaged portion of the permanent mains. At this point the lines of hoses were again connected to a manifold which was, in turn, connected to the main.

As is well known, centrifugal pumps of this type cause considerable trouble unless special precautions are taken to extract the whole of the air out of the pump and its connections, thus ensuring that these are completely full of water before the pump is put to work. Arrangements were made for this to be carried out by means of suitable ejectors and shutting down the sluice valves on the delivery manifold, these valves being slowly opened as the pump began to deliver water. It was found that a number of modifications had to be made in the general arrangement before the charging system was made completely satisfactory. Finally, this plant was made in every way as flexible and easy to operate as the small plant. It was realized that flexible hoses are not suitable for long continuous work and therefore arrangements were made for the bigger installations to have as part of their regular equipment steel pipe-work which could be sent with them and bolted together as soon as this could be conveniently arranged after the first emergency had been met by the flexible hose arrangement.

Trunk and Distribution Mains.

It has been previously stated that wrecking of these mains occurred to some considerable extent during the latter part of the last war, but during the present war the damage has been on a much greater scale, although the main principles to deal with the damage have not changed. These are roughly as follows :—

(1) If a street has been damaged by a number of bomb craters and several mains fractured, then a decision must be made as to the priority of the repair work and the order in which mains are required to be taken into use.

(2) If the mains are destroyed over a considerable distance, then it may be necessary to insert sluice valves at each end of the damage so that the mains may be charged from opposite directions. This, in turn, brings further complications if there are connections to the mains along the portions which have been destroyed.

(3) It may be necessary to make cross-connections between the various mains owing to damage being caused at other points.

(4) The most suitable way to isolate the fractured portion of the main is to cut the main in two behind the damaged part and at this cut to insert an ordinary sluice valve which can be strutted by timber. As soon as this has been done, the main can be charged as far as the valve and arrangements can be made at this point to insert manifolds so that as a temporary measure lines of hoses or temporary steel pipes can be laid along the surface of the road to the opposite end of the main where a similar valve and manifold have been inserted, thus by-passing the damaged portion. A pumping plant can be connected to these lines of hose, should it be necessary to raise the pressure in the main beyond the point of fracture.

The distribution system of most water undertakings only requires small mains at the boundaries owing to fewer people having to be supplied, but in times of emergency, as sometimes happens, large supplies are required at short notice close to the boundaries; the pumping plant was designed also to meet this contingency, the method being as follows:—

Two arrangements have been adopted, the first provides for dividing valves being fixed in the main some distance inside the boundary and on each side of the valve a branch is fixed to which hose manifolds are connected. By this arrangement a pumping plant can draw water from one side of the dividing valve and pump into the main on the opposite side of the valve and so increase the carrying capacity of the main supplying the boundary district by increasing the pressure in the small main.

The second requires a group of hydrants being fixed on each side of the dividing valve, to which the suction and delivery hoses of the pumping plant can be connected.

When a pumping plant is required to be put to work at the site of a destroyed pumping station, it is necessary to clear away the debris of the buildings and machinery and bring the portable plant as close as possible to the main suction culvert; at this point the temporary suction pipes are put down, culverts and delivery hose or temporary pipe-work laid along the ground to an undamaged part of the trunk pumping main where a connection can be made as already described.

It must be borne in mind that it is quite as important to have as complete an organization for main repairs as for the handling of the emergency machinery, as the machinery is of no use if the trunk mains cannot be used.

Portable Generating Plant.

Photograph No. 1 shows a complete set of portable generating plant on the road ready for travelling.

The first lorry is loaded with hose, steel pipework for rising main and tools, etc.

The second lorry is loaded with winch, shear legs and tools required for lifting gear. This lorry is towing the turbo-alternator.

The remaining tractor is towing the water-tube boiler complete with hot well and feed pump.

The whole convoy can travel along ordinary roads at about 20 miles per hour.

When arriving at the site of the damage, the lorry drivers are used as part of the crew for erecting the plant, and these men have all been drilled into exactly the work which they are required to do.

Six men all told are able to place the plant in position, and, providing no special obstacles are encountered, erect the shear legs, lower the pump to a depth of 150 feet, connect the boiler to the turbo-alternator, make the necessary connection between the alternator and the pump, raise steam and put the plant to work in eight hours.

Photograph No. 2 shows the boiler and alternator actually at work.

The large pipe on the extreme left-hand side of the photograph is the flexible delivery pipe from the submersible pump, delivering to the turbo-condenser.

The six 2¾" hoses are the deliveries taken from the outlet of the condenser and either go direct to the pumping main or to the suction of the pressure-increasing pump.

The only connections between the boiler unit and the turbo-alternator unit is the flexible metallic main steampipe and the flexible india-rubber pipe which takes the condensate from the condenser back to the feed pump hot well on the boiler carriage.

Photograph No. 3 shows a portion of the damage caused by a bomb during the last war to high pressure mains crossing a railway arch. The photograph

Photo. 1.

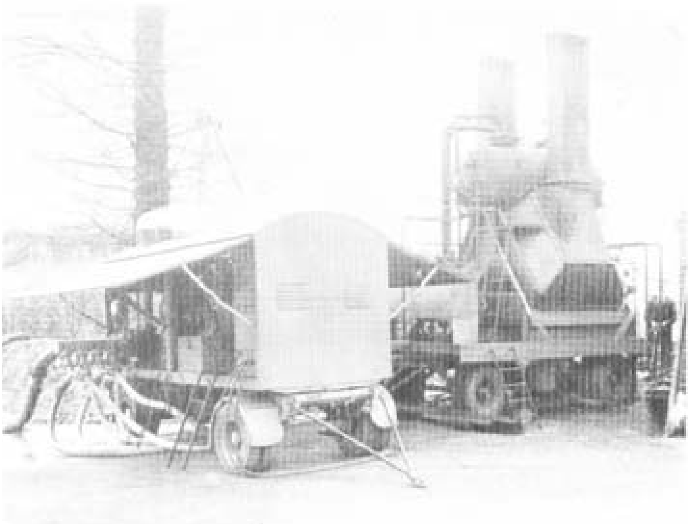


Photo. 2.

Emergency mobile water supply plant photo 1 & 2.

Emergency mobile water supply plant photo 3.

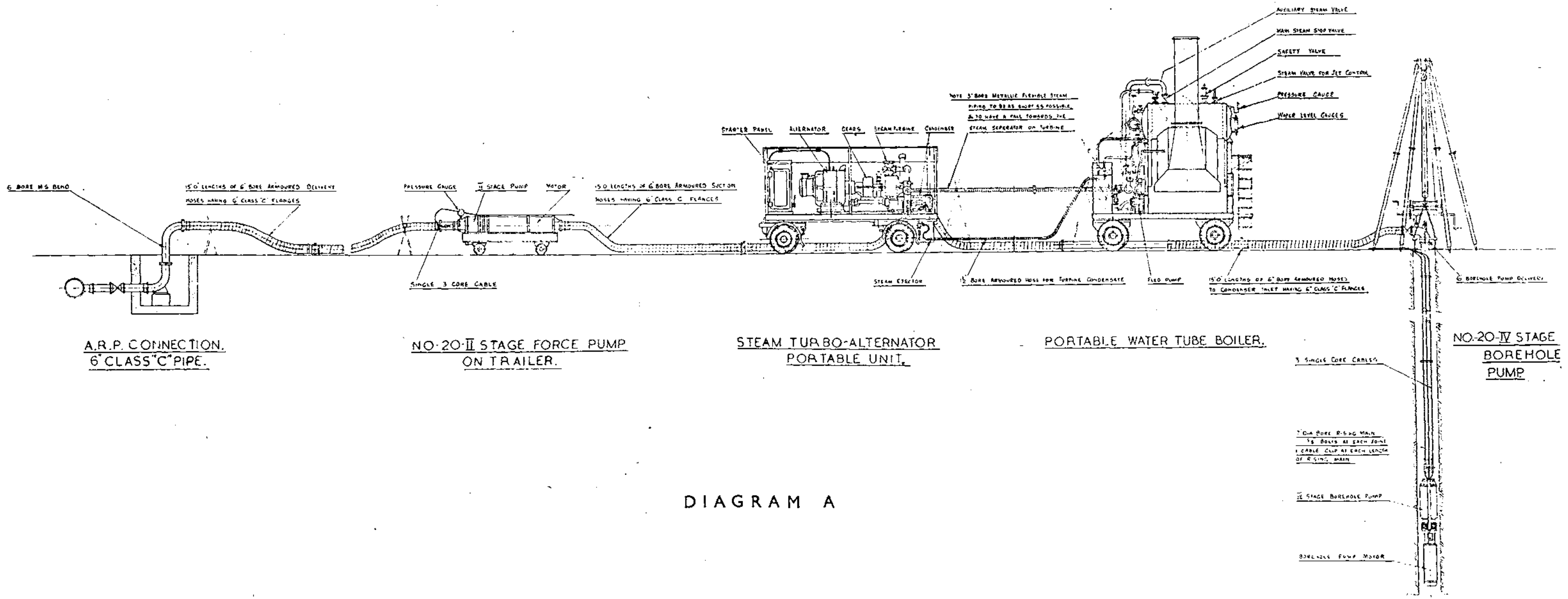
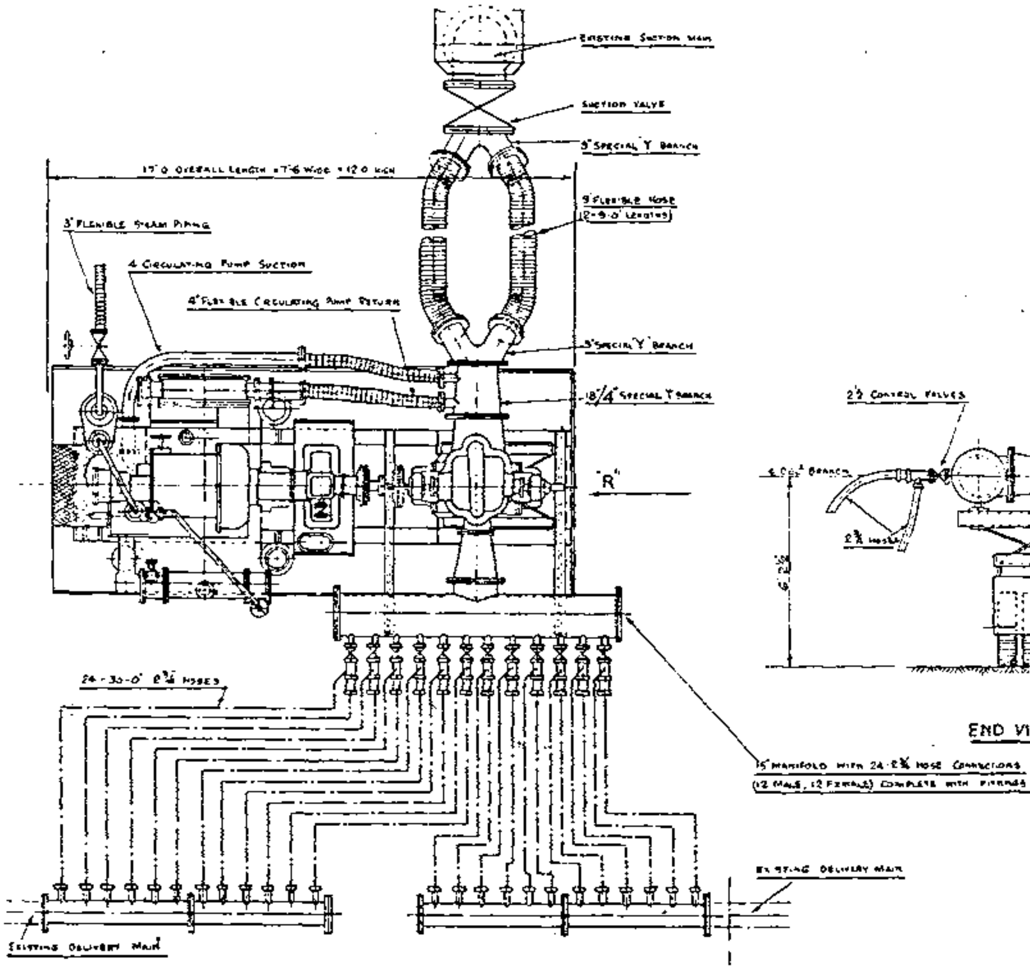
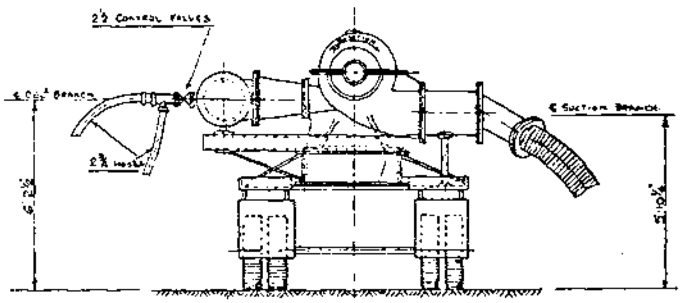

6 BORE M.S. BEND
15'0" LENGTHS OF 6" BORE ARMOURED DELIVERY HOSES HAVING 6" CLASS "C" FLANGES
PRESSURE GAUGE
II STAGE PUMP
MOTOR
15'0" LENGTHS OF 6" BORE ARMOURED SUCTION HOSES HAVING 6" CLASS C FLANGES
SINGLE 3 CORE CABLE
STARTER PANEL
ALTERNATOR
GEARS
STEAM TURBINE
CONDENSER
NOTE 3" BORE METALLIC FLEXIBLE STEAM PIPING TO BE AS SHORT AS POSSIBLE, & TO HAVE A FALL TOWARDS THE STEAM SEPERATOR ON TURBINE
STEAM EJECTOR
1½" BORE ARMOURED HOSE FOR TURBINE CONDENSATE
FEED PUMP
AUXILIARY STEAM VALVE
MAIN STEAM STOP VALVE
SAFETY VALVE
STEAM VALVE FOR JET CONTROL
PRESSURE GAUGE
WATER LEVEL GAUGES
15'0" LENGTHS OF 6" BORE ARMOURED HOSES TO CONDENSER INLET HAVING 6" CLASS "C" FLANGES
6" BOREHOLE PUMP DELIVERY
3 SINGLE CORE CABLES
⅝ BOLTS AT EACH JOINT
1 CABLE CLIP AT EACH LENGTH OF RISING MAIN
IV STAGE BOREHOLE PUMP
BOREHOLE PUMP MOTOR
A.R.P. CONNECTION. 6" CLASS "C" PIPE.
NO-20-II STAGE FORCE PUMP ON TRAILER.
STEAM TURBO-ALTERNATOR PORTABLE UNIT.
PORTABLE WATER TUBE BOILER.
NO-20-IV STAGE BOREHOLE PUMP

DIAGRAM A





END VIEW ON PUMP AS ARROW "R"

ARRANGEMENT OF 350 B.H.P. STEAM TURBINE.

4/8 M.G.D., SINGLE STAGE CENTRIFUGAL PUMP ON TRAILER.

DIAGRAM B

does not give a very good idea of the damage, as several other large mains were also damaged in addition to the two 36"-mains which can be seen. The damage, however, was fairly typical of what may be expected when several large mains, all in the same road, are burst at the same time, as not only is a large amount of damage caused by the bomb, but the high pressure water from the mains themselves frequently causes complete havoc, as they wash the ground away from other mains and cause them to burst even if they have not been damaged by the bomb, and in this particular case a great deal of damage was also caused by water flooding a railway cutting.

Diagram A shows an outline arrangement of a submersible borehole pump and surface pump, driven by one of the standard turbo-alternator equipments.

Diagram B shows flexible pipe connections for steam driven turbo-centrifugal piping sets.

AIRFIELD CONSTRUCTION DURING THE INVASION BATTLE.

By T/LIEUT.-COLONEL G. T. DENISON, O.B.E., R.E.

IT is with considerable trepidation that the author has undertaken to write an article on the subject of airfield construction, as several factors make the writing of such an article a difficult problem. The first is that of security; it will be realized that details of methods to be adopted, plant used and establishments cannot be divulged in such an article. The second is one of topography; obviously the proposed theatre of operations would have a tremendous effect on the exact method to be adopted. The third is that overseas there are many Royal Engineer officers who have had considerable experience of airfield work in active theatres of war and who are therefore fully qualified to point out any inaccuracies which follow.

It is proposed therefore to point out the various problems which may face the airfield engineer, to demonstrate the size of the job and leave it to Royal Engineer officers to work out their own solutions. The opinions expressed are the author's own, they have no official sanction, and quite frequently have the opposite reception.

In a recent postcript to a B.B.C. news bulletin Professor C. E. Inglis stated, as far as can be remembered, that there was a large amount of most difficult engineering work which was never even realized by the layman. He was referring to the engineering work which has to be carried out underground and illustrated his text by a description of the work involved in the construction of the Simplon Tunnel. Airfield work is very similar to this unseen type of engineering; although not underground it is mostly on the surface of the ground and that is the chief difficulty. The design of a large building or bridge is, as far as the visible portions are concerned, an exact science. The various factors likely to be encountered are calculable to a considerable degree of accuracy. It is only in the calculations for the foundations for the buildings, the abutments for the bridge or footings of its piers, that the really difficult and frequently incalculable factors are encountered. To a similar extent, airfield work descends from the comparatively simple stage of the exact science into the pit of unknown and frequently changing factors which face the engineer who has to deal with Mother Earth.

Among the chief factors which have to be considered are:—

(*a*) Aircraft design.
(*b*) The earth.
(*c*) Water.
(*d*) Weather.

These will now be considered individually and in detail.

The aircraft designer, in the case more particularly of fighter aircraft, is engaged in a constant race with his German opposite number in producing faster and more manoeuvrable machines carrying an ever greater load of armament. This results in greater wing loading of aircraft, higher stalling speed, with consequently longer landing or take-off runs. Even if runways 2,000 yards long were universally adopted to-day it would be a rash statement to suggest that finality had been reached.

As for bomber aircraft the designer has one primary object and that is to continue increasing the bomb-carrying capacity of his machines. The result is that certain types of heavy bomber have an all-up weight of more than 30 tons. When such a machine is landed in an awkward manner, dropping the last foot or two at roughly 100 miles an hour, a considerable impact is produced, no exact figures being available. A point that might be overlooked is the considerable weight of even single-engined fighters, some of the latest types, although they look small machines, weigh as much as 3½ tons.

There is another failing common to all aircraft at present in use. When landing, and just before the machine first touches down, the landing wheels are stationary; at the moment first contact is made these wheels are accelerated to about 100 miles per hour in an incredibly short space of time. Even on smooth concrete runways large clouds of smoke from the tyres are indications of the quite considerable amount of rubber which is burnt off when first contact is made. On dry grass the grass itself is actually burnt off in a patch where the first touch down occurs, in the case of some of the really heavy bombers. This action means that considerable care must be exercised to ensure that no sharp stone chippings are left on the finished surface of a hard-surfaced runway, or projecting wires in Sommerfeld Track runways for fighter aircraft.

Loads imposed on runways or turfed landing grounds by heavy bombers are sometimes not fully realized. The load on each wheel of a fully laden Stirling is slightly in excess of 15 tons; it is believed that no other single wheel commonly met with in engineering practice carries such a load; even single wheels on the heaviest locomotives do not approach this figure. This load is ameliorated slightly by the fact that the tyres of these heavy bombers are not high pressure, normally being pumped to a pressure of 42 lbs. per square inch for the forward wheels and 64 lbs. per square inch for the rear wheel. This allows the machine to operate from well established turf, but only when it is dry and firm. On the other hand, because good turf (which is, when dry and really firm, the best form of landing surface) does not grow in America, almost all flying on that continent is carried out from hard surfaced runways. American aircraft have been designed with this end in view; they are equipped with small wheels with correspondingly high pressure tyres. Any Royal Engineer officer who is faced with the provision of landing grounds for these machines should bear this important point in mind and provide correspondingly strong runways to counteract the tendency for these small wheels to punch through the surface.

In the case of single-engined fighters in particular it must be remembered that the forward visibility when landing or taxi-ing is very restricted and direct forward vision is completely obstructed by the nose of the machine. This has two awkward repercussions :—

(*a*) Runways have to be very wide indeed, standard width in the United Kingdom being 50 yards, or in the case of Sommerfeld Track runways 15 rolls wide or 52 yards.

(*b*) When taxi-ing the aircraft has to move in a series of jinks from side to side of the runway or taxi-track, as the pilot cannot see straight ahead when the tail of the machine is down. This entails frequent application of the brakes on alternate wheels, constant braking overheats the linings and there is a grave risk of the brakes binding. If this happens there is every chance that the aircraft will go up on to its nose. The lesson for the airfield engineer is obvious; single engine fighters cannot be expected to taxi long distances to obtain dispersal, for re-fuelling or to get into position on runways.

Regarding the difficulties presented by the earth itself to the engineer, much could be written. It is not proposed, however, to go into details about the various types of sub-soil which may be encountered. These vary tremendously throughout the world, from the good types such as gravel and loamy sand to the poorer types such as clay, chalk, peat, and abroad alluvial deposits, loose sand and cotton soil. In a large number of possible European theatres of operation there is a super-abundance of airfield sites on clay, with, or without, a chalk sub-soil. Under good summer conditions such a surface is excellent both for working construction plant and for flying the lighter fighter aircraft. Under winter conditions such sites become untenable, as vehicles bog themselves and aircraft tip up on their noses. The governing factor which must never be lost sight of is that in the long run it is the earth itself which will have to bear the total load placed on it; any artificial runway is only a means of distributing this load.

Water is one of the airfield engineers' chief worries, and one of the major causes in rendering natural landing grounds unserviceable. When starting work on the rapid construction of an airfield on a new site the question of drainage always arises. The first question which may have to be settled is whether or not the site chosen has sufficient natural drainage to dispose of the maximum anticipated rainfall in a reasonably short time, *i.e.* in about six hours. This water disposal is achieved by several methods such as run-off, either on the surface or beneath the surface, percolation through the surface, by evaporation, or absorption by the vegetation, or by a combination of the methods mentioned. Owing to the extreme flatness demanded by the R.A.F. on airfields the best method of drainage, *i.e.* run-off on the surface, is usually denied. Unless the landing ground is on a sub-soil with good percolation properties such as is provided by gravel or sand it will normally become unserviceable after heavy rain. In order to guarantee permanent serviceability on such airfields artificial run-off by sub-soil drainage will probably be necessary and the engineer is faced with the problem of providing such drainage. On a full-scale bomber airfield this presents a major problem as the work involved will employ anything up to 150 men for a period of about six weeks, will require large quantities of transport and materials and a certain amount of specialized mechanical equipment such as trenching machines.

Whenever impervious hard-surfaced runways are provided in parts of the world where heavy rain may be expected, the provision of a full drainage scheme to take the water from the runways must be catered for, and the earlier the drainage is installed the easier will become the work on the airfield.

The above are a few of the general problems facing the airfield engineer; in war the army engineer is faced with some extra problems which present some peculiar features. These may be sub-divided as follows:—

(*a*) Transportation.
(*b*) Mechanical equipment.
(*c*) Supply of materials.

Transportation will always present a major difficulty in war. Requirements for an airfield are always excessive, but such excessive demands are forced on the engineer by the very short time allowed to him by the General Staff. If a fighter airfield is required in the forward areas and if, owing to the state of the ground, it is found necessary to lay 100% Sommerfeld Track for two runways and the minimum of perimeter track, between 200 and 240 three-ton-lorry loads of Sommerfeld Track alone are required. Incidentally, this form of track is the lightest available; the tendency in future tracks will be towards an even heavier pattern requiring even more transport. As the General Staff may order the airfield to be in operation two or three days after the site has been captured, and as at least twelve hours of daylight must be allowed for laying the track, it will be seen that a serious administrative problem is set to the staff to provide the necessary transport and the road space to get the materials to the site. When permanent construction becomes necessary a much larger problem has to be faced; this is dealt with in more detail later. The particular Transportation problem is absolutely controlled by the time factor; if the General Staff can be induced to allow a little more time for completion of the work, it automatically follows that the major difficulties are at once greatly eased.

Airfield construction calls for a considerable quantity of mechanical equipment of the heavy earth-shifting variety. This raises several problems, the first being one of maintenance. Ordinary army methods of maintenance through L.A.D's, and R.E.M.E. workshops break down as these organizations carry no spares for mechanical equipment. Maintenance has, therefore, to be carried out by the headquarters of the mechanical equipment company, which carries a large section with breakdown equipment and adequate stores facilities. In the field, mechanical equipment sections can be separated from their parent company headquarters, but from the maintenance angle permanent detachment of sections should be avoided at all costs.

No fixed establishment for mechanical equipment on an airfield can be laid down as this varies considerably, not only being dependent on the theatre of operations, but also on the availability of the plant and the possibility of getting it on to the site. In general terms any airfield, where earth shifting will be required at all, will require the following plant, numbers of each type being dependent on the circumstances mentioned.

Heavy tractors. These should be of the D7 or D8 variety, all should be fitted with angle-dozer blades. Wherever possible for airfield work specify angle-dozers and not bull-dozers. A decision must be made as to whether the tractors should be fitted with Hyster Winches or Power Control Units (P.C.U.) The Hyster Winch is invaluable for tensioning Sommerfeld Track, pulling out trees, dealing with bogged vehicles and similar jobs where a really powerful winch is necessary. The P.C.U. is required for operating mechanical equipment of the trailer variety such as scrapers and rooters.

Medium tractors. These should be of the D4 type. Must be fitted with angle- or bull-dozer blades as well as Hyster Winches or P.C.U's as above. These are useful for lighter work than the D7 or D8 and can often be got on to a site where for certain reasons the heavier tractors cannot be got there.

Scrapers. 8 yard to work with a D7 or 4 yard to work with a D4. These are used to remove a lump, carry it, and spread it into a hollow. In common with most earth-shifting equipment the efficiency of the scraper is entirely dependent on the length of haul required.

Rooters. Heavy (K30 Le Tourneau), Medium and Light. The heavy rooter is most useful for grubbing roots and more particularly for rapidly grubbing up a road which a runway might have to cross. A K30 would be able quickly to deal with any normal type of road except the really heavy reinforced-concrete main roads. The heavy rooter can only be pulled by a heavy tractor of at least the D7 type.

Excavators. R.B. 10 or ½ yard; R.B. 19 or ¾ yard. These are capable of adaption at short notice to numerous requirements by using different attachments. The most useful on an airfield is probably a dragline, also carrying crane hooks and grab so that it can be used as a mobile crane. Other attachments are skimmer, back-acter and face-shovel. For general airfield work it is suggested that if three excavators are in use, the following attachments should be provided :—two draglines with crane hooks and grab and one each of skimmer, face-shovel and back-acter.

Graders. The best type to use is the auto-patrol. Graders are required to produce the necessary finish to a job on which angle-dozers and/or scrapers have been working. The heavier plant cannot work to a great degree of accuracy, a tolerance of plus or minus one inch representing considerable skill on the part of the operator. The auto-patrol, although a large and heavy machine, is capable of working to very close limits.

Dumpers. 1 yard or 2 yard capacity. Used to move earth a considerable distance; but dumpers should be mechanically filled, *e.g.* by a dragline, if they are to be employed economically. Also very useful for bringing materials such as mixed concrete or gravel on to a site which is not firm enough to take lorries.

Rollers. Heavy 8 to 10 tons, light 2½ tons. The heavy roller is required for road consolidation or repairs to hard-surfaced runways. Under no circumstances should it be allowed on to a turf surface when moist or it will ruin surface drainage by "panning." The light roller, preferably fitted with wide wheels, is of great value on natural surfaces for removing slight irregularities such as mole hills and rolling-in filling of wheel tracks which might occur. It is considered that the medium roller of from 4 to 6 tons is not of great value on an airfield as it is not man enough for the road or runway work and it is too heavy to be used on a natural surface.

Pumps. Although hardly mechanical equipment, heavy duty pumps are essential in the ground preparation stage ; it is asking for serious trouble to back fill a crater full of water with ordinary earth. A crater full of water presents two alternatives. The first is to back fill almost solid with hard material which will mean a considerable carriage of material, and the second, and probably easier, is to pump out the water. Providing the water can be disposed of adequately, a self-contained engine-operated pump of the 3-inch contractors' diaphragm type is probably the best, as these can pump dirty water. At least 200 feet of delivery hose per pump should be provided; unfortunately this hose is an awkward load for lorries as it takes up a considerable amount of space.

The above plant is by no means easy to move in the theatre of operations. Certain plant cannot move for more than about 5 miles on roads, so has to be carried, and each piece of plant has to be considered on its own merits. In general the following methods of moving the plant have to be adopted :—

Tractors have to be carried on tank transporters or on trailers towed by heavy A.E.C. Matadors or Scammels. Data are obtainable showing the combinations of tractors that can be carried by various tank transporters, but details cannot be given in this article.

Scrapers. 8 yard, should be towed by a Matador. 4 yard scrapers can be towed by a three-ton lorry providing there are no long or steep hills to be negotiated.

Excavators must be carried on low-loading trailers towed by a heavy vehicle such as a Matador. Even so, the height of a R.B. 19 on its trailer is 13 feet 6 inches. Excavators cannot be mounted on high tank transporters if any low bridges exist on the route.

Rooters and rollers also have to be carried, the 2½ ton roller can be carried in a 3-ton lorry but heavier rollers and rooters have to go on trailers.

Graders, if of the towing variety, can be towed by a 3-ton lorry. The auto-patrol is capable of travelling any distance under its own power, but only at 7½ miles in the hour.

Dumpers are similar to the auto-patrol. They use a lot of petrol.

A convoy of mechanical equipment is a most awkward one on the roads. It is a Class 40 convoy and can only move at 7½ miles in the hour. Loaded tank transporters and trailers are both long and wide loads, requiring at least, a width of 12 feet on roads. Such a convoy passing along a two-way artery may, for a short time, have the effect of reducing it to single width. A D7 angle-dozer on an Albion tank transporter has an overhanging blade about 10 feet from the ground. Recently such a loaded transporter was in convoy when it had to pull out to pass a stationary horse harnessed to a milk cart. At the critical moment the horse shied and in order to avoid slaughtering the beast the transporter driver pulled farther out to his right and in doing so cut a neat slice, with his angle-dozer blade, out of the roof of a bungalow which happened to be too close to the side of the road. Such incidents are almost bound to occur with this type of load.

Appended is a copy of an unofficial report, received by the author, of the arrival of such a convoy at the end of a three hundred mile march. It illustrates some of the problems encountered.

"Arrived O.K.—not without our little adventures. In fact judging by to-day's run from Exeter, the convoy has left a trail of amazed faces the whole way.

'Prancing Nellie'* chasing a herd of cows downhill at about three times

* "Prancing Nellie" is the Auto-patrol. It is a fearsome looking machine, looking very like a praying mantis, but 25 feet long.

normal cow-speed had to be seen to be appreciated, as did also the tank transporter's passage over Barnstaple Bridge, the overhanging cat-blade nearly 'scraping' the hats off the heads of the pedestrians on the footway.

But perhaps the funniest thing of all was its passage through a narrow village street where a water main was being laid, there being barely room for the load under normal conditions. The gentlemen digging the water trench all ducked. There was no need for them to, because the overhanging blade was well above their heads—but I sympathized with them. On the opposite side to the trench was a stone wall—along which the blade just scraped. Half-way along this wall was a speed limit sign, sticking out prominently as speed limit signs should. I have never seen a speed limit sign turn round so quickly!

Whilst standing in Barnstaple for refuelling, the exhibits were surrounded by spectators, 'Prancing Nellie' being a source of wonder to a bunch of girls. The Sapper driver, with commendable enterprise, proceeded to lean the front wheels, to the amazement of one young lady who shouted 'Mind, Lily, its going over!' Lily minded, and in doing so showed much more leg than she should have done: all of which shows the superiority of the Sapper mind (I should never have thought of it) and a new, novel use for the machine."

Mechanical equipment is the airfield engineer's best friend, as it saves literally thousands of man-hours. A word of warning must, however, be given; injudiciously used it becomes an absolute menace. If heavy tractors are allowed to run riot over the ground when it is really wet the site will quickly be turned into a morass. The golden rule to observe is to disturb the natural surface of the ground as little as possible if a rapidly constructed airfield is required.

The supply of materials becomes a formidable undertaking, especially when hard surfaced runways, etc., have to be provided. For a full bomber station with one 2,000 yard runway and two 1,400 yard runways, perimeter track, aircraft dispersal taxi-track and aircraft standings, the following areas of hard surfacing are required (approximate figures only):—

One runway 2,000 yards long by 50 yards wide	100,000 sq. yds.
Two runways each 1,400 yards long by 50 yards wide	140,000 sq. yds.
5,000 yards run perimeter track 50 feet wide	85,000 sq. yds.
50 dispersal standings each 100 feet square	55,000 sq. yds.
Taxi-track to dispersal, 3,000 yds. at 50 feet wide	50,000 sq. yds.
Total	430,000 sq. yds.

The above figure represents the construction of 35 miles of 21 ft. wide, or double width, roadway.

If concrete construction is adopted six-inch mass concrete has to be used to provide for the heavy loads imposed. Considering the quantities necessary these work out at:—

Cement	20,000 tons.
Sand	40,000 tons.
Aggregate	80,000 tons.
Total	140,000 tons.

If the General Staff require the airfield to be finished in a period of three months, which appears to be a normal requirement, daily deliveries of materials will amount to:—

Cement	222 tons.
Sand	444 tons.
Aggregate	888 tons.
Total	1,554 tons.

The above is only theoretical. In order to complete the work in three months, daily deliveries will have to be in excess of this figure, rising at times to 1,800 tons.

The quantity of transport required will naturally depend on the length of carry, method of transport used, and methods of loading and unloading the materials. Probably the best method is by train; if this is used sidings and methods of unloading capable of discharging four trains a day must be provided.

Where road transport is used lorries must be of the tipping variety, the 6-ton tipper, which can carry a reasonable load, being the most manœuvrable. At the quarries or sand-pits mechanical methods of loading must be adopted, unloading at the airfield by tipping. The numbers of lorries, dependent on the factors mentioned, are worked out as an example.

(*a*) Length of carry—say 30 miles. Hours of daylight—12. Lorry capacity —6 tons.

(*b*) Three trips per day might be obtained, but drivers would require relief.

(*c*) Number of lorries required to deliver 1,800 tons of sand, cement and aggregate per day would become 100.

(*d*) Lorries must be laid off one day per week for maintenance. This represents 15% addition, a further 10% addition must be made for replacements.

(*e*) Total number of 6-ton tippers required will therefore be 125.

Sand and aggregate must be obtained in sufficient quantity to meet the above requirements. Where quarrying has to be carried out the bottleneck will occur over crushing the stone. It may be assumed that 1,000 tons of crushed stone will be required daily; to meet such a commitment two large crushers, each capable of crushing at least 50 tons an hour, will be necessary.

A point which might be overlooked is the large quantity of water which will be required at the site; this will be in the nature of 30,000 gallons per day and it may necessitate a special bore hole.

It is realized that the above calculations are based on mass concrete construction, as this is probably the best method under normal circumstances. There are, of course, other methods, such as sand stabilization using a cut-back bitumen, mix-in-place as is used in the Middle East, and cement earth stabilization as used in America with success. These require considerably less transportation than mass concrete; on the other hand, methods such as hand pitching with two-coat tar macadam (standard Air Ministry practice) or grouted soling, as used in Malta, require considerably greater quantities of materials to be moved.

Up to the present only the runways, etc., have been considered. When hard-surfaced impervious runways are supplied adequate artificial drainage must be provided. On an average bomber airfield this means the provision of about 100,000 foot run of piping, varying in size from 4 inches to 24 inches, the excavation and removal of perhaps 50,000 cubic yards of earth and the bringing on to the site of 50,000 tons of gravel. There is also the provision of certain essential buildings to enable the aircraft to operate, access roads and camouflage, all of which require transport and materials.

The above problems will always face the Royal Engineer officer who is engaged on airfield construction. During the invasion battle certain further slight complications are added, these are dealt with in detail. For sake of clarity the provision of airfields has been divided into three categories, this division is not arbitrary and it may be assumed that a clear-cut distinction will in fact develop when the battle starts.

(*a*) Provision of the first fighter type airfields immediately following the landing.

(*b*) Provision of subsequent fighter type airfields.

(*c*) Provision of semi-permanent and permanent airfields for heavier aircraft.

Considering these in chronological order. The provision of the first airfields presents some peculiar problems of its own. If the General Staff require these to be ready for operations within three or four days of the time of the initial landings, it follows automatically that large numbers of men whose primary role is airfield construction will have to be landed during the assault stage. Every man landed during this stage must be a combatant soldier fully capable of taking his place in the battle during the assault landing. The men must therefore be trained to a high degree of military training and also in combined operations. In other words there is no room available in assault craft for specialists, no matter how good they are at their own work, if they are likely to be passengers from the fighting point of view.

If landings are made on a hostile coast it may be assumed that existing dock facilities will be damaged and that they will take a long time to repair. All men, plant and materials for the initial airfields will therefore have to be transported in assaulting craft and taken through water up the beaches. The various types of L.C.T. and L.C.M. which may be used for this purpose are designed for landing tanks and other military vehicles; they were not designed for landing elaborate mechanical equipment. Before an operation which envisages the landing of plant under these conditions is carried out, detailed trials in order to train the drivers is absolutely essential. No details of trials, which may have been carried out in the past, can be given in this paper but a few general hints might come in useful.

(*a*) The problem cannot be solved in an office or off a drawing board by measuring width of plant and comparing it with the entrance of a craft or its ramp. Any vehicle or plant which has a clearance of under about 15 inches must have the approval of the Royal Navy and trials should be undertaken.

(*b*) A simple piece of plant like the very small 2½ ton roller may cause the greatest trouble. In actual fact the roller can only be brought on and off craft either on a trailer or lorry or by winching. If the latter method is used both leading and preventer tackles must be attached; this may take an appreciable time thus holding up the discharging of the craft.

(*c*) Certain plant may take a considerable time to unload; on a falling tide the Royal Navy may not be prepared to run the risk of grounding the craft until refloated by the next tide.

(*d*) Certain mechanical equipment, such as excavators, has a high centre of gravity. This might seriously alter the position of the centre of gravity of the loaded craft in relation to its metacentric height and thus render the craft unstable. This tendency is aggravated when the excavator is loaded on a trailer.

(*e*) The loading of certain plant on trailers in landing-craft requires special precautions in chogging and lashing of the trailer and, more particularly, of its load to prevent the load sliding off the trailer in a heavy sea.

(*f*) Loading of landing-craft requires detailed study. Is this to be carried out from dry land or by lowering the plant into the assault craft from the parent ship? If the latter method is tried in a high sea there is a reasonable chance of the mechanical equipment punching a hole through the deck of the landing-craft.

(*g*) Certain craft have steep humpback entrances, this means that some plant may belly on this hump. Chogging gets over the difficulty but it slows down the procedure for loading and unloading the craft.

(*h*) Once the plant has landed it has to wade through at least three feet of water before it reaches dry land. Although elaborate instructions, giving every detail, exist on how to waterproof standard vehicles, no such instructions have been prepared for plant. The principles of waterproofing must therefore be applied to suit the particular machine, but even so there is a considerable danger that some unnoticed place may not be blocked up and water getting in might cause trouble. Not only must the prime-moving portions of the plant be protected, but precautions must also be taken to stop sea water getting into the working mechanisms such as the drums of the P.C.U. on a tractor.

Men, plant, transport and materials will all have to come over the beaches, so the next difficulty is encountered. Everything must, of necessity, be cut to the barest necessities, and then drastically cut again. A percentage, which must be settled by the General Staff, might then be added to allow for sinking during the landing stage.

If it is decided that Sommerfeld Track, or other form of artificial runway, will be necessary, the General Staff may decide that the R.A.S.C. lorries which have to take the track up to the site will be loaded with track at the base from which the expedition starts. This decision is naturally dependent on priorities, but if the method is adopted it greatly assists the operation of bringing stores ashore. The standard 25-yd. coil of Sommerfeld Track used for airfields weighs just over 5½ cwt. and is an awkward load to land over a beach.

As all transport must be reduced to an absolute minimum, cars even for senior officers will have to be left behind, certainly in the early stages. Airfield reconnaissance and other communication work will have to be done on motor cycles. Officers engaged on this work must be fully competent to ride motor cycles, not only on poor roads, but also across country. Owing to the difficulty of riding motor cycles under water it is considered advisable to bring these machines ashore in vehicles.

Until the first airfields are produced, the aircraft operating from them, and the expedition reasonably well established, there is every possibility that the enemy will have local air superiority. If he obtains this it is likely that all movement on roads will be restricted to the hours of darkness. In addition to slowing up deliveries to the airfield site such a restriction would mean that during the hours of darkness the traffic on the roads would be excessive and transport required for airfield work would have still further to be cut.

Bearing in mind the above restrictions and difficulties, and assuming the necessary minimum of men, plant and materials have been landed, the actual construction or repair of an airfield follows on the same lines as the provision of subsequent fighter type airfields which will now be described.

In an area where there are several possible sites the General Staff, in consultation with the R.A.F., should specify the following points :—

(*a*) Type of aircraft to be catered for.
(*b*) Approximate orientation of the main runway.
(*c*) Time by which runways are required.
(*d*) Whether single runways are permissible, or must airfields have two intersecting runways more or less at right angles to each other.
(*e*) Is speed of primary importance, or should efforts be made to find a site which at a later date might be possible of development into a bomber airfield ?
(*f*) Order of preference of sites (if any).

In the United Kingdom it has been decided that after the General Staff have given their preference of sites or areas in which airfields are to be located, the choice of the actual site, or sites, on the ground must be left to the C.R.E. and his R.A.F. adviser, final approval from the " G " angle being obtained by the C.R.E. before actual movement to the site starts. This ruling, naturally, only applies where several possible sites may be available.

Assuming the advance is taking place where there are several sites available, the procedure for the rapid reconnaissance and approval of the site chosen is all-important. In general the procedure is to push forward small airfield reconnaissance parties with the leading infantry brigade headquarters, these parties, consisting of about two officers and four other ranks. They are moved forward, under orders of the brigade, on to the site as early as possible. These small parties carry out quick preliminary reconnaissance, reporting at the earliest time by D.R. or wireless to the C.R.E., who will probably be situated at advance divisional headquarters, whether or not the site is possible. Later a very brief report is sent back to the C.R.E. stating approximately the amount of work to be carried out together with an estimate of the men, plant and materials required.

When the second reports are received the C.R.E. should be sufficiently in the picture to go forward with his R.A.F. liaison officer to the best site. Approval from the engineering point of view is given by the C.R.E., approval from the flying point of view having to be obtained from the R.A.F. officer. Final concurrence has to be obtained from the General Staff to ensure that no sudden developments in the battle have drastically altered the plan.

During the reconnaissance stage the C.R.E. may expect to find himself surrounded by a clutter of other reconnaissance officers. Before the R.A.F. can operate from the airfield a large quantity of "ground staff" will have to be installed. Ground defences, A.A. protection, signals and aircraft servicing facilities will have to be in operation, and, *in toto*, this may well mean that 1,000 men to provide these facilities will be in place before the first aircraft arrives. Reconnaissance representatives of both the heavy and light A.A. Gunners, the R.A.F. Regiment, R.A.F. Servicing Commandos and Air Formation Signals will almost certainly wish to be present with the C.R.E. It has been established that these representatives will have no say in the choice of the site, this being entirely the responsibility of the C.R.E. and his R.A.F. officer; but as these other arms are dependent on this decision and as they themselves are also pressed for time, their reconnaissance officers will probably be with the C.R.E. The R.A.F. Regiment and certain A.A. Gunners should even be in place while the airfield is being constructed. The duty of the men building the airfield being to get on with the work as quickly as possible without having to break off constantly to deal with enemy interference.

The advance and deployment of the airfield unit should be in two stages. A small advance party, equipped with as much mechanical equipment as can be allowed on the roads, should arrive, if possible, 4 to 8 hours in advance of the main body. The tasks of this advance party, which should largely consist of Sappers, are as follows:—

- (*a*) To open up the site so that the main body can deploy on it. This may entail repairs to road approaches, or the laying of a pilot road on the site to enable vehicles to get on to it.
- (*b*) To clear mines and booby traps which the enemy may be expected to leave on any existing airfields.
- (*c*) To prepare a "crash strip" at a very early date.
- (*d*) To undertake the unexpected engineering task.

A "crash strip" is a strip about 600 to 800 yards long by about 30 yards wide where a damaged aircraft can get down without causing serious injury to the pilot. It is not in any sense of the word a runway, as it is not proposed to fly the machine off again, so it is not necessary to place any form of tracking on the crash strip. The work involved includes the filling in of any craters, pulling gaps in hedges and removing any other serious obstructions on the ground which might completely break up an aircraft. When finished the crash strip must be well marked, the easiest method being to use ground strips, which are an R.A.F. supply. The crash strip should, on no account, be placed within 100 yards of the outside line of the proposed final runway as the crash strip will be required by the R.A.F. while the main runway is being prepared.

The main body, with the remainder of the mechanical equipment, should then arrive and deploy along the runway and perimeter track if necessary. These must have previously been marked out by either the reconnaissance party or the advance party. All craters should be pumped out if full of water, back filled by plant where possible and consolidated both by plant and hand ramming. Hedges may have to be grubbed up, differences in levels between neighbouring fields graded out, and minor undulations removed. Buildings and trees, or other obstructions in the flying approaches, will have to be removed.

This work will probably take quite a long time. An airfield engineer will be lucky indeed if he can complete this preparatory work for one runway and a portion of perimeter track in a European theatre of war with 800 men in 24 hours. In many cases it will take a matter of several days, and it may well take weeks if heavy grading is involved. If Sommerfeld Track has to be provided it would be preferable for it all to arrive together during the hours of darkness after the ground preparation has been finished. This, however, is dependent on when "Q" can provide the transport. It may be necessary to accept track in small lots spread over the preparatory and track-laying stages.

The men required for constructing the airfield will have to be equipped with picks, shovels, matchets, rammers, stone forks and wheelbarrows. Wheelbarrows should, if possible, be rubber tyred; if hard wheels are used on a wet site, planking for running the barrows along will be necessary or there is a grave risk of the site becoming a quagmire and useless for flying at a later date. A considerable quantity of explosives are also required for clearing flying obstructions, a compressor truck also coming in useful for this work.

Laying of Sommerfeld Track is a rapid process. When properly trained a team of 60 men can lay a 250-yard length 52 yards wide, tension it, and picket it down in 12 hours of daylight. A D7 tractor is necessary for tensioning; although the work can be done by a D4 it takes more than twice as long as the track, then has to be tensioned in two halves. However, the actual laying of the track is only similar to putting a roof on a house; it is only the finishing touches. It is once again emphasized that is it the preliminary work required in the ground preparation which may take a very long time.

The men required for this work must be really fit. They will, in the majority of cases, have to march to the site; so they must be trained to march at least 20 miles a day. After a short rest they must then be capable of an intensive 12-hour task on the airfield; they may then have to go on repeating this work for some weeks or even months. Work on an airfield is of an exacting nature as it means much heavy lifting and when track-laying a man must work in an unnaturally bent condition which is very trying and the work is fully exposed to the weather. Finally the men will probably come in for serious attention by the enemy. Men must be fully trained in the use of their weapons, in elementary tactics and in aircraft action. They must all be trained in the loading, unloading and laying of Sommerfeld Track. A proportion of one Sapper company with four Pioneer Corps companies has proved a success. The Sappers in such an organization must be specially trained in the detection and removal of booby traps and mines, use of explosives and the clearing of obstructions.

The construction of semi-permanent and permanent airfields for heavier aircraft is a major engineering problem. Hard-surfaced runways will be required. Once these become necessary the engineer is faced with the transportation problem mentioned earlier. Such airfields are a long-term policy and, of necessity, will take months to build. Planning for them must start at a very early stage. Because these airfields will take so long to complete, and as they will require such large quantities of transport and materials, it is considered that they cannot be built in the forward battle areas as are the fighter types previously described. The labour engaged on this work need not, therefore, be trained to the same degree of military training as men for the forward airfields. Ordinary Line of Communication Engineer units, such as artizan works companies, mechanical equipment companies, road construction companies, electrical and mechanical companies, quarrying companies and well-boring sections will be required and have sufficient technical knowledge to carry out the work. The labour required, as it will be of a static nature, does not have to march long distances so need not be trained in this respect. In fact, during a large scale invasion it may be possible to recruit and use local labour, providing such labour is not in a half-starved condition. It is of interest to note that during the German advance through Greece, prisoners of war were employed by the enemy on the construction of forward landing grounds. In effect, the building of permanent airfields might be considered a normal works service, with the all-important proviso that the directing staffs on an airfield must be specialists in this type of work. They must also be fully competent to organize large quantities of mechanical equipment and labour as well as being able to solve the numerous technical difficulties encountered on an airfield.

In conclusion it might be stated that airfield construction, from the point of view of the Army generally and the Sapper in particular, is an unmitigated nuisance. In order to exploit fully the efficiency of the R.A.F a frighteningly large number of airfields will be required. The construction of these is bound to hold up the rate of advance of the army, and even when built the R.A.F. alone cannot win the land battle. However the reverse of the picture has been clearly demonstrated in the history of the war to date ; unless an air umbrella is provided to the army the chances of a successful invasion are slight. The provision of adequate air support is entirely dependent on the provision of airfields suitable for the types of machines to be used and in sufficiently large numbers.

A COMMON SUSPENSION BRIDGE.

By COLONEL A. C. SHORTT.

ALTHOUGH the ability to improvise is rightly claimed to be part of the essential stock-in-trade of a Sapper, opportunities for applying it practically in the course of normal training are of comparatively rare occurrence. This is due partly to the advent of standardized bridging equipment which has tended to make us " meccano " minded and partly to the lack of essential ingredients which, if not in short supply, are usually so rigorously controlled that the collection of sufficient stores for the exercise of anything more ambitious than the most elementary stick-and-string craft has become an operation in itself.

* * * * *

On the face of it, the prospect of spending the summer months encamped in the heart of the Highlands offered great opportunities for a little back-to-nature engineering. Mountain torrents merging into wide, swift-flowing streams, and deep wooded ravines opening into broad valleys, with riverbanks varying from shallow pebble strands to precipitous hillsides, presented an attractive variety of bridging problems. While, here and there, lumber camps in which timber of every sort and size was to be found in profusion, seemed to provide the solution to problems of supply.

We had reckoned however, without the Timber Control.

Tentative requests for the loan of spars for training had been met, by our friends the foresters, with goodwill and a desire to co-operate ; but Whitehall was adamant, and it was not until the provision of temporary communication between two Brigade Group camps, separated from each other by River " X," assumed sufficient importance to be pronounced operationally necessary, that our proposals to carry out some improvised bridging received the stamp of official approval.

* * * * *

The camp areas extended for 5 miles along either bank ; but access roads limited our choice of site to a short stretch of river near " A," where we were fortunate in finding an ideal setting for a suspension bridge, with approaches over well drained heath and meadow land, conveniently situated with reference to the two camps. Banks were level, firm, and sandy, with 9 inches to 1 foot of topsoil ; the overall gap being about 180 feet. Having decided, in principle, that a suspension bridge was " on," our first task was to take stock of possible resources.

Command approval was given for us to buy what spars we needed from a nearby Forestry Unit, who were most co-operative and allowed us to select our own trees for cutting. Poles, averaging 6 inches in diameter, of a suitable length for roadbearers, were also to be had in quantity from the local defence dump ; but the majority of them had been salved from the shores of the firth, where they had been immersed in sea water for upwards of two years ; and they were of doubtful quality.

This, however, was only a beginning. A few rapid calculations disclosed a formidable list of stores requirements : S.W.R., bulldog clips, tackles, blocks, falls, pickets, etc., in quantities far exceeding the resources of our Field Park Company, who carried only the normal quantity of assorted loot over and above their G 1098 equipment. The role of Fairy Godfather was played by O.C. " X " T.B.R.E., who lived not over many miles away, and who kindly gave us the run of his fieldworks store. Two 150-fathom lengths of brand new 3" S.W.R. ; a pile of old 12" x 4" planks (relics from some forgotten bridge); and a few precious bulldog clips were among the more important items plundered from his store.

* * * * *

The problem was to provide a bridge to carry led pack animals in pairs over a gap of 180 feet. The bridge was likely to be in constant use for about 5 months, at the end of which time it was to be dismantled and returned to store.

The limiting factors were cables and decking. The latter was difficult to obtain and we had barely half the foot run of 12" x 4" that we needed. We reckoned, however, that by cutting what we had to half thickness we could just make do. Of the three 3" S.W.Rs. which were long enough for the job, two—the two borrowed from the T.B.—could not be cut. For the main towers transoms and anchorages, up to any diameter of green felled timber was available : bulldog clips were at a premium and had to be used sparingly throughout : while, since rope lashings were virtually non-existent, 14-gauge wire had to be used as a substitute.

It was decided to arrange the cables as follows. One of the two new 150-fathom S.W.Rs. was used, double, for each of the main cables, with a 50-fathom length from either end of the third S.W.R. laid in with each double cable, the slack of the third cable being carried across the anchorage on the near bank. Each main cable thus consisted of a triple 3" S.W.R. These were *laid*, and not used as suggested in *M.E.* Vol. III, as independent ropes seized along their lengths. Our reasons for doing this were that the ropes appeared to be of different manufacture, and it was thought that, with the three laid together, a frictional grip between them could be relied upon to equalize the strain at the point of attachment of sling to cable. We thought that no extra stretch would result ; but in the event we were proved wrong, as is shown hereafter.

* * * * *

Two of the Field Companies were already in camp, at work on water supply and other camp services ; the third was preparing to start special training with its Brigade Group. Time was of no particular object, so it was decided to treat the job primarily as training, in order to give as many N.C.Os. and men as possible an opportunity of handling heavy spars and experiencing " trapeze " work over a wet gap. Working parties varied in size and composition according as Sections could be made available from other work ; no useful records of time and labour were therefore kept. Many shortcomings in basic training manifested themselves during the course of erection ; but the greatest interest was taken by all ranks (including the Staff and other arms of the Division) in what was, for these days, a somewhat unusual performance.

* * * * *

Design. Within the limits imposed by the shortage of materials our problem was straightforward. The class of load had to be limited to that which could be carried by two triple 3" cables, and the design had to be modified accordingly

In calculating the load on the cables we found that the figure given in *M.E.* Vol. III for Cavalry in half sections produced a tension greatly in excess of the maximum allowable stress. This figure (400 lbs./ft. run) is however, for "Cavalry in marching order, crowded at a check to the greatest possible extent." The load could therefore be reduced by imposing a limit spacing on traffic crossing the bridge. The normal practice is for one driver to lead two pack animals. A limit spacing was therefore imposed of 7 lengths between pairs.

Taking the weight of two pack animals and the driver as 3,000 lbs., and assuming seven pairs to be on the bridge at the same time, the maximum (live) load on the cables amounts to 21,000 lbs. : say 150 lbs./ft. run E.U.D.D.L. over the 180 ft. span. Assuming a figure of 120 lbs./ft. run for the weight of the superstructure, the maximum tension in the cables (from Table XLII) is therefore :—

$$\frac{1.346 \times 270 \times 180}{112} = 584 \text{ cwts.}$$

Tension in each cable is therefore 292 *cwts.*
Safe stress in a 3″ (new) S.W.R. is $12c^2 = 108$ cwts.
Therefore a triple cable is strong enough.

For the main towers, simple rectangular trestles, braced and strutted, were decided upon.

Height of pier = Dip in cable + camber + length of shortest sling.
= 18′ (1/10 span) + 3′ (1/60) + 3′ (To allow for screening).
= 24 *feet.*

$$\textit{Thrust in pier legs} = \frac{270 \times 180}{2240} = 22 \text{ tons.}$$

Therefore thrust in each leg = 11 *tons.*
From Table XXIII a 12″ mean diameter spar is ample. In fact, we used 14″ spars.
Length of cable (from Table XLII).
Length between piers = 1.027 × span = 185 *feet.*
Length between tops of piers and anchorages = 2 × 2.7 × height of pier = 130 *feet.*

Length for fastenings = 2 × 40 feet = 80 *feet.*
Total 395 *feet* (or 66 fathoms).

Each cable measured 150 fathoms, and was long enough, therefore, to be used double.

Anchorages.

Cables were assumed to be 10 feet apart. Cable ways 2′ 6″ wide. End overlap 2′ 6″.

Overall length of log = 10′ + 5′ + 5′ = 20 feet.
Effective length = 15 *feet.*

$$\text{Effective area of face (assuming a 14″ diameter spar)} = \frac{15 \times 14}{12} = \text{(say) 18 sq. feet.}$$

$$\text{Pull per sq. foot of anchor face} = \frac{65{,}408}{18} = 3{,}634 \text{ lbs.}$$

From Table XXXV the safe depth is 5 feet. In fact, our anchorages were 7 feet deep.

$$\text{Maximum intensity of sheer} = 32{,}704 \times \frac{1}{\pi \times 14^2} \times \frac{4}{3} = 71 \text{ lbs./sq. in.}$$

From Table XX, Group II timber is amply strong. In fact, the anchorage log was packed out to 24″ diameter at the bearing surfaces.

Slings. The formula for the length of a sling is $y\left(=\frac{4\,dx^2}{a^2}\right)$ + camber + length of shortest sling.

Where d = dip.
x = distance of sling from centre of the bridge.
a = span.

Assuming a 9′ bay, and camber 1 in 60, *i.e.* 4″ per bay:
Numbering outwards from a pier:—

No. 1 *Sling* Length $= \frac{4 \times 18 \times 81 \times 81}{180 \times 180} + 2'8'' + 3' = 20'2''$

No. 2 *Sling* Length $= \frac{4 \times 18 \times 72 \times 72}{180 \times 180} + 2'4'' + 3' = 16'\ 10''$

No. 3 *Sling* Length $= \frac{4 \times 18 \times 63 \times 63}{180 \times 180} + 2'0'' + 3' = 13'\ 9''$

And so on. A total of 19 pairs of slings in all.

Size of Slings. Maximum load on transom = 49 cwt. (See under Roadbearers).

Therefore maximum load on one sling = 25 cwt.

$12c^2$ must exceed 25. Therefore a $1\frac{1}{2}''$ S.W.R. is strong enough. In fact 2″ S.W.R. was used.

Decking. In calculating the strength of the decking, we assumed that the worst possible case was when three-fifths of the total weight of a man and a horse is brought on to one foot of the horse, centrally over a span of 2 feet (assuming 5 roadbearers). Our decking was $1\frac{3}{8}''$ Group III timber.

$M_{ff} = \frac{420 \times 12}{2240}$ in./tons = 2.25 *in./tons.*

$M_r = \frac{rbd^2}{6} = \frac{3 \times 12 \times 11 \times 11}{6 \times 8 \times 8} = 2.27$ *in./tons.*

Therefore decking is just strong enough to resist bending.

Maximum Shear = 420 lbs. Average intensity $= \frac{420 \times 8}{11} = 25$ *lbs./sq. in.*

Maximum intensity $= \frac{3 \times 25}{2} = 38$ lbs./sq. in.

From Table XX, safe working stress is 100 lbs./sq. in.

Although the decking was theoretically strong enough using 5 roadbearers, we thought it advisable to increase the number of roadbearers to 6, in view of the uncertain quality of the timber (see below).

Roadbearers. The worst load on a transom was assumed to be the equivalent dead load of one pair of pack animals with their driver, plus the dead load of one bay of superstructure.

Weight of two animals and driver	= 3,000 lbs.
Impact Factor	= 1,500 lbs.
Weight of bay of superstructure	= 1,080 lbs.
Total ..	= 5,580 lbs.

Assuming 5 roadbearers and using the field formula

$$\frac{W}{n-1} = \frac{6}{10} \times \frac{d^3}{L}$$

where n is the number of roadbearers, and d the minimum diameter.

$$d^3 = \frac{49 \times 10 \times 9}{4 \times 6} = 184$$

Therefore a 6″ diameter spar is just good enough. As stated above, in view of the doubtful quality of the timber, it was decided to add a sixth roadbearer. The arrangement is shown in Figure 1.

Transoms and *Grillage* were calculated in the normal way. 10″ spars were used for transoms: 3′ lengths of 12″ × 5″ for grillage.

Details of struts and back guys are shown in Figure 1.

Lateral stability was given to the bridge by the normal methods of

(i) Waisting. The width of the roadway was reduced from 10′ at the towers to 7′6″ at the centre of the span.

(ii) Decking diagonally. See Figure 1.

(iii) Attachment of wind bracing from opposite ends of the centre bay to shore anchorages, as shown in Figure 1; and cross bracing each span with cordage. This was particularly necessary owing to the exceptional wind in the locality; and to the possibility of a rise in tide over bank level.

In addition to side screens, made of camouflage netting, it was found advisable to fix slabwood guard rails up to a height of 2′ 6″ from the roadway, to prevent animals from stepping over the ribands. These were lashed: not nailed. It was also found that about ½″ of earth, strewn on the bridge for the first 10 feet or so, accelerated the traffic. On only one occasion were animals observed to refuse to go on to the bridge.

* * * * *

Erection.

An aerial ropeway, using sheers and a 2″ S.W.R., was erected alongside the site to transport the lighter stores to the far shore. The heavier spars were floated across and parbuckled up the bank. No difficulty was experienced in towing the triple cables across the river, a muddy bottom affording sufficient grip to prevent the strong current from sweeping the cables downstream. Spars for the main towers had to be barked (how we missed an adze!) and, in the case of the cap and ground sills, slotted to take the legs, the latter being secured with 14-inch drift bolts and dogs made up by the Field Park Company. Owing to the fact that the footings were some 2′ 6″ below the general level of the ground, it was comparatively easy to erect the towers by man-handling, with assistance from a tackle and lever spar operated from the opposite bank; foot ropes being made fast to Ordnance holdfasts.

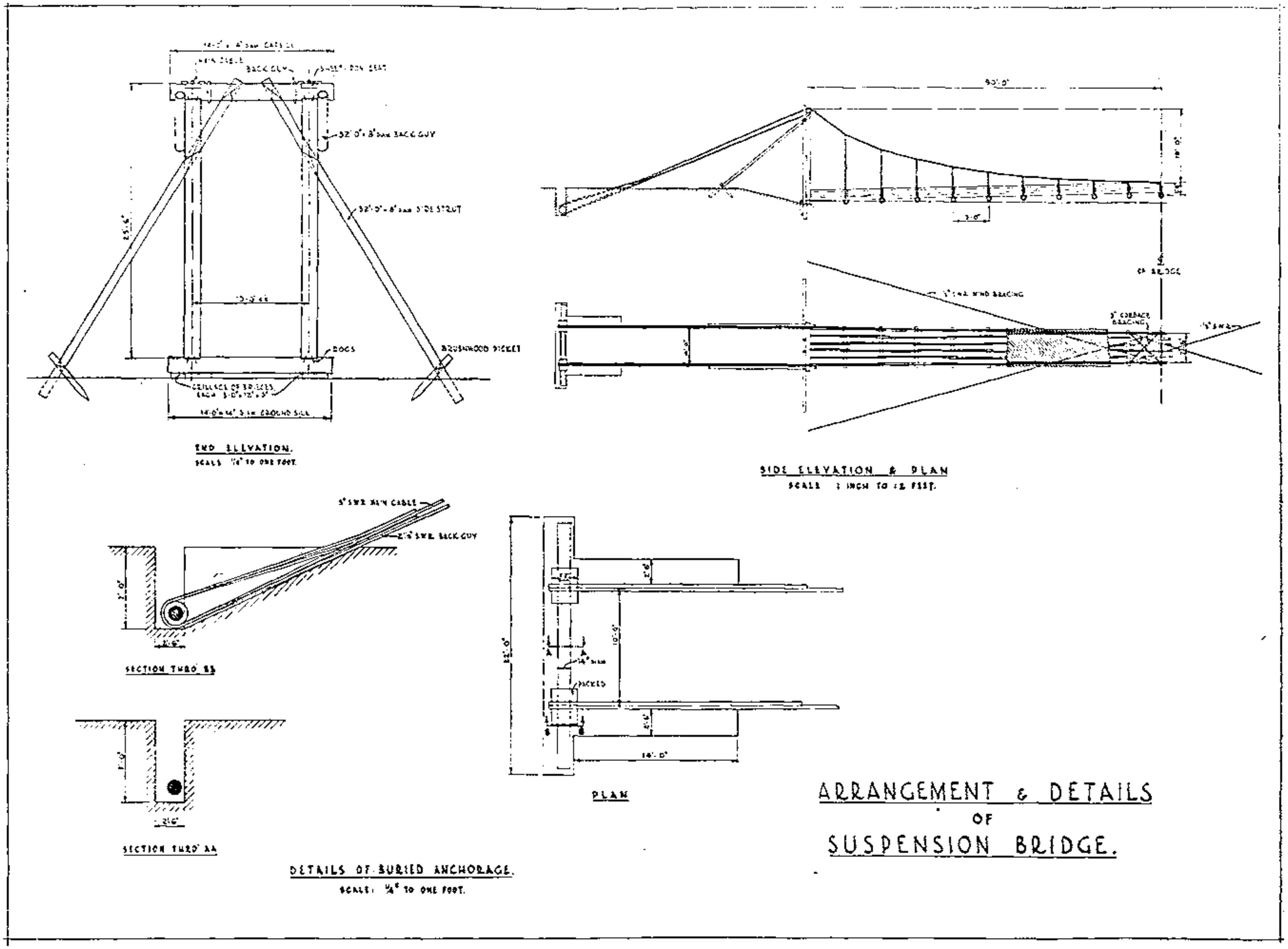
The construction and erection of the towers, and the lowering of the heavy anchorage spars into their trenches, showed up a general ignorance of the use and application of power, *e.g.* levers and parbuckles. The spars were green and full of sap, and the weights greater, in consequence, than N.C.Os. and Sappers had been accustomed to handling. With very little tuition the latter quickly picked up the knack of applying power at the right point in the right way, which seemed to justify the time spent in giving detailed instruction during the building of the bridge. Knotting and lashing were anything but perfect when it came to (*a*) using wire instead of rope, and (*b*) working several feet overhead, using one hand only, with a swift flowing river below. One Sapper, to give an example, when required to put a clove hitch on a spar at a point 20 feet above the ground, climbed laboriously up the spar and asked for one end of the lashing to be thrown up to him. The idea of putting the hitch on the spar at his own height and sliding it up had not occurred to him. Where articulation was necessary, square and diagonal wire lashings were invariably made too tight. N.C.Os. appeared, at the start, to be very set in their ideas, and lacked adaptability.

The chief difficulty lay, as we anticipated, in correctly estimating cable stretch and allowance for bedding-in of anchorage logs. In the first instance 4′ 6″ to 5′ vertical height at the centre of the span was allowed for stretch. By the time all the slings, transoms, and roadbearers had been attached, the sag had overshot this allowance by nearly 2′. The whole of the superstructure was then dismantled, while the tension was taken up in the main cables (by means of a simple tackle attached to each cable with a 3″ rope stopper), a further allowance of 2′ being made for any additional stretch. Even this was insufficient, as is shown in the photograph, which was taken before the final adjustment to the bridge after the cables and anchorages had been given adequate time to settle. The excessive stretch was probably due partly to the newness of the S.W.Rs. and partly to our having laid them. From observations kept on the anchorages there appeared to be very little forward movement of the logs. Incidentally, it is advisable, when erecting the main towers, to allow for this anchorage settlement by keeping them at a slight slope outwards from the gap until tensioning is

A common suspension bridge photo 1

Photo. No. 2.—Later in the training season the bridge was dismantled and re-erected as shown above on another site.

A common suspension bridge photo 2


END ELEVATION.
BRUSHWOOD PICKET
DOGS
SIDE ELEVATION & PLAN
PLAN
SECTION THRO' BB
SECTION THRO' AA
DETAILS OF BURIED ANCHORAGE.
ARRANGEMENT & DETAILS
OF
SUSPENSION BRIDGE.

complete. It is a simple matter to ease them forward if too much allowance has been made; it is not so simple to haul them back once they overshoot.

The cables were looped over the tops of the towers with very little difficulty, the standing end of the cable being held by a stopper, in each case, while the running end was looped and hauled up by a man astride the capsill.

Points of general interest.

Traffic control is essential. It should start before the last cover is left. Original calculations were based on the assumption that animals could be kept to single file; it was then learnt, as stated above, that normal practice is for one driver to lead two animals, and design was modified accordingly. Finally, one morning when the sick parade had been exceptionally large, a column was seen to be crossing the bridge with *three* animals abreast. The N.C.O. in charge, when remonstrated with, argued that the first lot seemed to get along all right so he let the rest follow! After careful observation of the behaviour of the bridge it was decided to allow three abreast in future—but controlled to 10 lengths between each group. Austin 7 cars and M/Cs. were also allowed, at suitable spacings.

Maintenance must be of the highest order, and continuous. This was fully realized, and, as a result, the bridge stood up well to much traffic, and fulfilled all demands made upon it. On one occasion, the bridge carried four separate columns, each consisting of 170 pairs of fully loaded pack animals, during the day. Apart from minor adjustments to decking, and re-positioning of slabwood sides, no other maintenance was necessary. A copy of the orders for maintenance parties may be of interest: it has been included therefore at the end of the article.

The absence of an adze in Field Company equipment was badly felt: box spanners for bulldog clips also came under the heading of essentials. Few tools or small stores were lost during the work of erection, thanks to our insistence that they should invariably be hung round the neck by a loop or cord.

It only remains to say that the Officer in charge of the bridge was Captain McVean, 2nd i/c of the Field Park Company, who, as Q.M.S.I. McVean of the Fieldworks School S.M.E. must be known to generations of young R.E. Officers who passed through his hands in days before the war.

Orders for Maintenance of Suspension Bridge.

1. Two men required, normal working hours.
2. Tools required are :—Box Spanner to fit 2" B.D. Clip.

Ditto	3" D.T. Clamp.
Ditto	2½" B.D. Clip.
Hammers	1
Saws Hand	1
Shovels	1
S.W.G.14	10 lbs. approx.
Recce. boats	1
Nails 3"	1 lb.
Spare decking.	3 pieces.

3. *Duties* :—(daily).

(*a*) On arrival, go over all clamps and B.D. clips and prove them tight.

(*b*) Inspect all seizings—renew where necessary.

(*c*) Examine decking for spacing and condition. Close up decking and renew where necessary. All loose boards, re-position and nail.

(*d*) Make good all wire holding down ribands, and ensure that no ends project into roadway. Where necessary, use packing pieces between wire on roadway side and the riband.

(*e*) Examine under-side of roadway, using recce. boat for this purpose. Ensure that all R.Bs. have a sufficient bearing. Adjust where necessary.

(*f*) Fill in all holes at immediate approaches to bridge as they occur.

(*g*) Sprinkle sand occasionally on the roadway.

(*h*) Control the traffic—if pack, in single file, spacing between animals should be 4 lengths.

If pack in pairs (*normal*) then spacing between each pair will be 7 lengths. When returning unloaded, pack animals will be led by muleteers dismounted.

(*i*) All animals will cross at the walk, and observe the intervals as above.

(*j*) Remounts will cross singly.

(*k*) Other traffic :—

(1) If in formation—in file at 10 feet intervals. (Breaking of step essential.)

(2) Austin 7's will cross at 5 m.p.h. at 50 feet intervals.

(3) Motor cycles in single file at 15 m.p.h.—10 feet spacing.

(*l*) No *other traffic* is permitted.

(*m*) Make good any damage to slabwood guards. Replace where necessary.

(*n*) In the event of the maintenance party having any doubt as to the proper functioning of the bridge, they will close the bridge to traffic, contact O.C. Company or nearest Engineer Officer, and report.

(*o*) Before leaving bridge they will make a final inspection and ensure that all is well.

[*Editor's Note.*]—In old days at Roorkee great stress was laid on the importance of the girder hand-rail for the sake of stiffening the bridge. I remember that in Aylmer's Panjkora bridge the girders were packed with brushwood as screens for the mules.

MILITARY MINING IN THE WAR OF 1914-18.

WRITTEN FOR THE CORPS HISTORY.

I. INTRODUCTORY.

IN the war of 1914-18 it was perhaps not surprising that Military Mining, the oldest application of engineering to the art of war, should be employed on a vast and unprecedented scale. As however the size of the underground operations carried out on the Western front is not always realized, the statement of three outstanding facts, which help to give some measure of the extent of this struggle, may not be out of place.

In 1916, when mine warfare had reached its height on the Western front, some 30 of the 80 miles of front held by the B.E.F. were protected by underground galleries, in several instances at more than one level. In some sectors, notably south of La Bassée, it was possible to walk along a continuous underground gallery in front of the British trenches for several miles.

During 1916, nearly 1,500 mines were fired by both sides on the British-German front, the majority not as part of any major or local surface attack, but in the process of more or less continuous underground warfare.

By the middle of 1916 the British had a total force of approximately 25,000 men actively engaged in mining.

It will be realized from the above that to describe in detail the numerous underground operations carried out during the war of 1914-18 is quite beyond the scope of this article. All that can be attempted is to give in outline the conditions which created the need for this intensive mining, the nature of the units formed in the Corps to carry out this work, and a brief description of their achievements. For more detailed information the reader is referred to the following two books on the subject :

Work of the Royal Engineers in the European War, 1914-19—Military Mining (W. & J. Mackay & Co., Ltd., Chatham, 1922).

Tunnellers. The story of the Tunnelling Companies, Royal Engineers, during the World War—by Captain G. Grieve and B. Newman (Herbert Jenkins, Ltd., 1936).

These two books will be referred to hereafter as *Military Mining* and *Tunnellers* respectively.

In addition to the above, *The Life of a Tunnelling Company* by Captain H. W. Graham (Hexham J. Catherall & Co., Ltd., 1927), being the experience of this officer in the 185 Tunnelling Company during the war, throws an intimate and interesting light on life within a mining unit.

II. Training in Peace—Mining Breaks out on the Western Front.

During the years immediately preceding the Great War little study or training in mine warfare was carried out in the Corps, though two units, the 20th and 42nd Fortress Companies R.E., received special training in this branch of engineering during the years 1911-14. These two companies went to France in August, 1914, with the B.E.F., in which they were, among their other functions, "earmarked for siege duties." Actually, however, they were the first units to be converted to Army Troops Companies, and took little direct part in the underground struggle that was shortly to develop. On the other hand, many of the Officers and N.C.Os. of these two units were drafted to the earlier tunnelling companies on formation, to provide the necessary nucleus of regular personnel.

The neglect to make a larger provision of trained personnel was largely due to the belief, then generally held, that any European war of the Great Powers would be quickly ended by one short decisive campaign ; protracted sieges, in which underground attacks would be useful, had no place in this pre-war conception. For the same reason no doubt, in spite of a significant instance of the attack and defence of trenches by mining during the Russo-Japanese war of 1904-05 (the first instance of the use of mining against field fortifications), the possibility of the employment of mining in trench warfare was given little consideration. Nevertheless it was exclusively in this new field that military mining was to be applied on such an extensive scale on the Western front.

Here the long period of position warfare, which commencing in the autumn of 1914 lasted for nearly four years, produced conditions up till then associated with fortress warfare. Improvement in weapons during the years preceding the war had conferred advantages on the defence the consequences of which it was difficult to foresee ; the strength of positions behind wire entanglements had become almost the equivalent of that of permanent fortifications of an earlier period. The two opposing systems of field works extended almost unbroken from the English Channel to the Swiss border, and therefore presented no vulnerable flanks. It soon became evident that decisive results could not be obtained by frontal attacks delivered on the then accepted methods of field warfare. A deadlock had been reached, in which many of the features peculiar to siege warfare were reproduced on a vast scale.

In many places the trenches were but a few hundred feet apart ; they were packed with men and there was no depth in defence, so that the tactical situation was favourable to mine attacks. In these the Germans were the first aggressors. The attack was apparently part of a general plan, for in December and January, 1914-15, German mines were exploded in a number of sectors from Lorraine to the plains of Flanders, notably, on the British front, at Givenchy and Cuinchy and in the Ypres salient.

To the British infantry in France, experiencing the first and in many respects the most trying winter of the campaign, a new horror was added. It was clear that immediate underground defensive measures were called for, as well as offensive mining in retaliation. Field companies, fortress companies and field squadrons started mining operations where the situation was most threatening. With their many other important duties, however, these units had neither the personnel and equipment, nor in many instances the necessary experience to cope with this new problem. To assist the field companies, officers and men with experience in mining in civil life were drawn from battalions in the line and formed into brigade mining sections, each of which usually consisted of one officer and about fifty other ranks. It was soon evident however, that this improvisation was not the final solution, and that the formation of engineer units specially organized and equipped for mining was essential.

III. FORMATION OF FIRST TUNNELLING COMPANIES, R.E.

In December, 1914, Major *Sir* J. Norton Griffiths, *M.P.*, 2nd King Edward's Horse, had written to the War Office stating that the engineering firm of which he was the head had a number of expert underground tunnellers and borers, who had experience in driving tunnels under London and other large cities. He suggested that these "clay-kickers," as they were generally known from their special method of tunnelling in clay, would be particularly suitable for mining in the Flanders clays. When, therefore, a decision to form special mining units was reached in February, 1915, Major Norton Griffiths was authorized to enlist miners for service in France, and the formation of eight tunnelling companies was approved by the War Office.

The need was so urgent that the first five tunnelling companies (170, 171, 172, 173 and 174) literally came into being in the front-line trenches, and elements of these units were engaged in active mining within a few weeks of their authorization. Miners or clay-kickers were enlisted one day, equipped at Chatham the next, and working underground in France within a fortnight of leaving their civil occupation. A considerable proportion of the personnel was also obtained by transferring to the Corps men of brigade mining sections and any other suitable infantry with mining experience who volunteered. Most of the new units were attached to field companies at the outset, but they quickly became independent. The formation of the remaining three of the first batch of tunnelling companies (175, 176 and 177) took place under rather less harassing conditions. 177 Company did not go into the line till June, 1915.

Officers were obtained either by granting commissions in the Corps to mining engineers, or by the transfer of officers with a knowledge of mining already serving in other branches of the Army. The earlier companies were commanded by regular R.E. officers. Later, as these became casualties or new companies were formed, selected war-time officers who had gained the requisite military experience were appointed to command. By 1918 all tunnelling companies were commanded by officers holding temporary commissions.

The establishment of these units was initially 9 officers and 283 other ranks, organized into H.Q. (including a small nucleus of regular personnel for administrative duties) and four sections. These numbers were soon found to be quite inadequate, and, after several increases, an establishment of 19 officers (including an adjutant and a medical officer) and 550 other ranks was finally approved. Each tunnelling company had in addition, for the provision of unskilled labour, a varying number of permanently attached infantry, often during the most intensive period of mine warfare as many as 500. Thus, not infrequently, the officer commanding was in control of over 1,000 men.

More details of the formation of the first tunnelling companies will be found in *Military Mining* and *Tunnellers*, but no account, however brief, is complete without some tribute to the genius and energy of Major Norton Griffiths, who was attached to G.H.Q. in France to advise and assist in the formation of these units. Apart, however, from his tireless enthusiasm for the task in hand, he was gifted with great foresight. It was, for instance, due to his insistence that tunnelling companies were provided with M.T. (4 three-ton lorries, 1 box car, 12 motor cycles)—the first Engineer units to be mechanized on any scale. To this wise provision not a little of the efficiency of tunnelling companies may be attributed.

In the matter of mining equipment, as well as personnel, much was needed. Many essential items were archaic in design, for the British Army had had no experience in mining since the Crimean War. The "Rootes Blower," an inefficient and exceptionally noisy rotary air pump was the only ventilating apparatus available; it achieved little except to attract enemy attention. An unwieldy and dangerously ineffective form of smoke helmet was all that was provided for mine rescue; listening apparatus was non-existent. Modern equipment, adapted after careful trials to suit active service conditions, had therefore to be obtained, or, as in the case of listening, special apparatus had to be designed for the purpose.

In 1914 black gunpowder was still the standard explosive for mine charges and it was used in most of the earlier underground attacks. High explosive, however, soon entirely displaced black powder, owing to the greater effect obtained. Guncotton was used at first, but disliked because of the large amount of carbon monoxide left behind in the ground. Ammonal was then adopted as the service explosive for mines, though occasionally guncotton, blastine and other high explosives were used instead. The problem of providing an adequate supply of explosive, always available wherever required, was a formidable one, for the amount of high explosive used in mine charges rose by leaps and bounds; in 1915 five tons was considered a big mine; in 1917 the record mine of 42 tons in one single charge was fired.

IV. Continuous Increase of Mining Activity during 1915. Formation of more Tunnelling Companies.

While this new force was organizing, mining activity continued to increase. During the spring of 1915 our infantry suffered casualties at several points as a result of German mines and the subsequent fighting. Brigade mining sections, reinforced by the first elements of tunnelling companies, as they became available, did their best to cope with the situation. These first efforts frequently consisted of narrow crooked galleries, too shallow for adequate defence. But if this work was not always effective, it served a great purpose in restoring confidence to the troops in the line—holding trenches, knowing that they may be blown up at any moment and that no counter measures are being taken, is sufficient to shake the stoutest of hearts.

Nor were these early underground activities entirely confined to the defensive. Numerous galleries were driven under the enemy trenches, from which mines were fired to assist infantry attacks and raids; one example was that of Hill 60. Here miners drawn from the 1st and 3rd Battalions, Monmouthshire Regiment, (T.A.), subsequently reinforced by a section of 171 Tunnelling Company, succeeded in driving under the German trenches three galleries from which mines were fired in conjunction with a successful infantry attack on 17th April, 1915.

By June, 1915, as has been shown, the first eight tunnelling companies had been formed and were in the line. Almost every week, however, mining broke out in some new sector of the front. In the same month the Third Army took over from the French a new front, north of the River Somme, where mining had also started. Five new tunnelling companies (178, 179, 180, 181 and 182) were formed to deal with the increased underground liabilities. Still the demand for mining units outstripped the supply, both on account of increased mining activity, and the growing extent of front held by the B.E.F. In particular the Vimy Ridge, taken over from the French early in 1916, added a sector in which intensive underground fighting was in progress. As a result twelve more tunnelling companies (183, 184, 195, 250, 251, 252, 253, 254, 255, 256, 257 and 258) were formed at various times during the period August, 1915, to June, 1916.

Moreover, underground operations were not entirely confined to the campaign in France. In the Gallipoli peninsula, mining broke out on the fronts held by the New Zealand Division* and the 29th Division in May, 1915, and soon spread to many sectors, for the nature of the soil was favourable and the tactical situation somewhat similar to that on the Western Front. Mining Sections from Australian, New Zealand and British infantry were formed on much the same lines as in France. Several mining attacks were launched at the opposing trenches by both sides and intensive mine fighting developed in which our forces gradually gained ascendancy. An account of the mining operations in this campaign will be found in *Tunnellers*, Chap. III. It was in Gallipoli that the 254 Company started active life, though arriving only shortly before the evacuation. This unit absorbed within its ranks the British mining sections already formed.

V. Mining Situation on Western Front at End of Year 1915-16.

In addition to the total of 25 British tunnelling companies already mentioned, the overseas contingents provided 7 (3 Canadian, 3 Australian and 1 New Zealand), and the Australian forces also formed a unit designated " The Australian Electrical and Mechanical Mining and Boring Company." This unit working over the entire British front proved of the greatest value to all tunnelling companies both British and Overseas, particularly in carrying out trial bores to obtain geological information and in the provision and maintenance of power plants for the illumination of mine galleries and subways.

Thus, by early 1916, had been assembled a vast force of miners which in numbers was not far short of the total of other engineer effectives engaged in the front line in France.

Tunnelling companies from their inception had been made Army Troops; a wise provision in view of the importance of these units remaining more or less permanently in the same part of the line, in order to gain an intimate knowledge of the local underground conditions. During 1915 the direction of the work of tunnelling companies was of necessity delegated to Corps or Divisions. With neither of these higher formations, however, nor with armies or G.H.Q., was there an expert to advise on the employment or administration of these new units. Chief Engineers and C.R.Es. did what they could to fill this role among their many other heavy responsibilities and duties, but the tactics of military mining in this war of position had become a specialized and intricate subject. Moreover, in a campaign where every battle overground had its mining counterpart below, co-ordination of underground policy and effort had become essential.

Thus the mining situation at the end of 1915 was far from satisfactory, and, although much valuable work had been carried out, there had been also much mis-spent energy and wasted effort. Units had frequently been pitted against trivial objectives quite incommensurate with the labour involved, and defensive systems had been put in where the likelihood of underground attack was remote

There was also still much room for improvement in technical equipment, but, until some centralized technical organization existed to collect and weigh the opinions of units in the line on such questions as power plants, listening apparatus and problems of a similar nature, the best solutions were unlikely to be forthcoming. Again, there was an obvious need for centralized control to compile records and data, and to disseminate items of technical importance to units. Hitherto facilities for the interchange of ideas and information on mining questions had been meagre.

*See *History of the New Zealand Engineers* (Evans, Cobb and Sharpe Ltd., Wanganui, N.Z.).

VI. Appointment of Inspector of Mines and Controller of Mines.

It was in these circumstances that on 1st January, 1916, Lieut.-Colonel R. N. Harvey was appointed "Inspector of Mines" at G.H.Q. in France, with the rank of Brigadier-General. General Harvey in his previous capacity as Assistant to the Engineer-in-Chief had been closely concerned with the formation of tunnelling companies from the inception of these units; he thus had first-hand knowledge of the task before him, while his unsparing energy and ready sympathy with the miner made the appointment both a thoroughly successful and happy one. To his staff, Major R. G. Stokes, an experienced mining engineer, who had seen service in the line from the start of mining on the Western Front, was appointed Assistant Inspector. Simultaneously with the formation of this Inspectorate an R.E. officer was appointed "Controller of Mines" to each army H.Q. with the rank of Lieut.-Colonel, with a technically qualified officer as assistant. The functions of these new appointments can be interpreted from the remarks in the preceding paragraphs; their precise duties and war establishments will be found in *Military Mining*, Part I, Chap. I.

The effect of the introduction of this specialized administration soon became evident. As has been seen, the Germans had gained a great advantage by an early start. Though during 1915 by vigorous local underground offensives the difficult task of driving the enemy back had been accomplished at numerous points, there were still many sectors of the line, particularly on the fronts recently taken over by the B.E.F., where the enemy were under, or dangerously close to, our trenches. With control now centralized it was possible to concentrate underground forces where they were most needed. It was on the First Army front from the La Bassée canal to the Vimy Ridge that the most intense underground fighting took place, and on this front alone over 800 mines were discharged by both sides during 1916. Gradually, however, under the direction of Lieut.-Colonel G. C. Williams, Controller of Mines, First Army, the enemy were driven back. Superiority underground was obtained both here and at other parts of the line where the situation had been unfavourable.

Our success was primarily due to the fact that we were now better organized and equipped than our opponents. Data obtained during and since the war definitely prove that on the average we drove galleries more rapidly than the Germans. Moreover, as a rule, we were quicker to get into our galleries after a "blow," either our own or the enemy's, and by this method gain ground before the opposition could take counter measures.

The spring of 1916 saw our trenches adequately protected against sporadic underground attacks at nearly all threatened points and at the same time, under the able direction of General Harvey, mining offensives, designed to help forward future major operations planned by G.H.Q., were commenced.

Technical efficiency under the new administration also made great strides. Gas poisoning, due to carbon monoxide formed from the incomplete combustion of charges, was a prolific source of underground casualties. In fact, during 1915 deaths from this cause considerably exceeded those inflicted by direct enemy action in mine fighting. In the autumn of 1915 men trained in mine rescue work in the coal mines at home had been enlisted to act as instructors to mine rescue squads to be formed in France and Lieut.-Colonel D. Dale Logan, R.A.M.C., an officer with experience in this work and in diseases peculiar to miners, was attached to G.H.Q. as adviser on these matters to the Engineer-in-Chief. On the appointment of General Harvey this mine rescue organization was absorbed in the Inspectorate. Schools were formed in each army for the training of men in the wearing of oxygen-breathing apparatus and mine rescue duties; rescue stations, adequately equipped with apparatus, were established in all sectors where mining was in progress; a supply of canaries and white mice, used to detect the presence of carbon monoxide was provided. A detailed account of this aspect of the struggle will be found in *Military Mining*, Part II.

Later in 1916 the scope of these army schools was extended to include instruction in all branches of military mining, in addition to mine rescue work. Various courses for officers and N.C.Os. were held in which instruction was given in the technique and tactics of mine fighting, the art of listening with and without instruments and the design and construction of mined dugouts. These mine schools were also used as establishments for carrying out experiments and testing mining apparatus.*

Geology was another field in which expert assistance was needed. With the Australian E. & M. Company already referred to had come Major T. W. E. David,† indeed, this eminent geologist played a prominent part in the raising of the Australian mining units. Major David became geological adviser to the Inspector of Mines. Thanks to his knowledge and indefatigable work, both in and out of the line, tunnelling companies were provided with geological information which proved invaluable in planning offensive and defensive mining operations. Detailed information was obtained on the extent and depth of the blue clay (the most suitable mining strata) in Flanders, the seasonal variation of water level in the chalk, and on many other questions of vital importance to the miner.‡

As regards improvement in equipment, the introduction of power plants had obvious advantages in the promotion of efficiency and reduction of man-power. Much was done in this direction in the matter of pumping, ventilation and lighting, though owing to the limiting conditions of trench warfare excavation by power tools did not prove very successful. Probably the most important technical advance was the introduction of the Geophone, a simple but most effective instrument for underground listening, invented during 1915 by a Professor at the Sorbonne University in Paris. The introduction of central listening stations in large mine systems was also an important step.§

VII. Offensive Mining in Major Operations—The Somme, Arras and Messines.

The opening of the offensive on the Somme in July, 1916, was the first occasion in which tunnellers were employed to assist the initial stages of the advance of a major operation. Although conditions were unsuitable for offensive mining, the sub-stratum being chalk, in which the approach of a gallery could be easily heard by the enemy, the mines fired were extremely successful. In addition "Russian saps" were driven in the surface clay across "no man's land" to provide advance emplacements for trench mortars and machine guns, or communication trenches to be opened up at zero hour. Trenches across "no man's land" were also formed by hydraulic pipe-pushers.**

Mines played little part in the Arras—Vimy Ridge offensive; the soil here was chalk and conditions unfavourable. By far the most important contribution of tunnelling companies to the preparations for the operation was an extensive system of subways—the first occasion of their use on a large scale. Battalions, on more than half the front, were able by this means to take up their battle positions from the safe seclusion of tunnels, and thus avoid disheartening and often disconcerting pre-battle casualties. In the Vimy Ridge sector twelve subways averaging half a mile in length were driven. In front of Arras, by driving some three miles of subways, a series of existing caves were connected up with the front line and with the covered-in moat of the town of Arras. Troops were thus able to descend underground in the centre of the town and travel in safety

*For further information see *Military Mining*, Part III, Chap. V.

†A memoir to the late Sir T. W. Edgeworth David will be found in *The R.E. Journal* of December, 1934.

‡For further details see *Work of the Royal Engineers 1914-18—Geology*,

§For further information see *Military Mining*, Part III, Chap. V,

**See *Military Mining*, Part I, Chap. IV, and *Tunnellers*, Chap. V.

to the front-line trenches some two miles distant. The caves also provided accommodation for 11,000 infantry and large quantities of stores. From the heads of subways communications across "no man's land" were provided by Russian saps or pipe-pushers as in the Somme offensive.*

The Messines offensive was launched on 7th June, 1917, to the accompaniment of the discharge of mines containing nearly 1,000,000 lbs. of high explosive on a front of 10 miles; the greatest mining operation in the history of warfare. The soil on this front was clay, in which, unlike the chalk further to the South, work could be carried out comparatively noiselessly. In these circumstances galleries, in some cases nearly half a mile in length, were successfully driven beyond the enemy front line under the forward centres of resistance of the defence. The attack on the Messines Ridge was originally planned to take place in the summer of 1916, and some of the mines fired in June, 1917, were actually laid as early as April, 1916. Repeated postponement of the offensive enabled the underground scheme of attack to be extended; on the other hand Lieut.-Colonel A. G. Stevenson, Controller of Mines, 2nd Army, and the units under his direction had an anxious and difficult task in maintaining the mines intact without revealing to the enemy that his positions were undermined. Apart from the material destruction and disorganization effected by the explosion of these heavily charged mines at zero hour, the effect on the morale of the defenders was simply staggering; Ludendorff in his memoirs is insistent that but for the employment of these powerful mines our infantry could not have effected a break-through on 7th June.†

Tunnellers played an important though less spectacular part in the preparations for the last great British offensive of 1917—Passchendaele. The soil was not particularly favourable to mining and, as explained in the succeeding section, changing conditions of warfare were rendering this form of attack less effective. Ten and a half tunnelling companies were employed on this front in the provision of underground accommodation, which experience was now proving to be so valuable. Battle headquarters for brigades and battalions, dressing stations, subways, O.Ps. and shelters for troops were all included in the programme of work. A congratulatory message from Sir Douglas Haig to the Engineer-in-Chief, in which the Commander-in-Chief refers to "the splendid work accomplished by the tunnelling companies," affords convincing evidence that the by now traditional efficiency of these units was well maintained.‡

VIII. Decline of Mine Warfare, Dugout and Subway Work.

As already stated, mining activity reached its height in the middle of 1916 and thereafter gradually fell away; underground attacks practically ended with the triumph of Messines.

The decline of mining activity in the latter period of position warfare on the Western Front may be traced to the gradual change in the conduct of the defence. In the earlier stages of the campaign conditions conducive to the maintenance of a strongly held front line obtained, and suitable objectives for mining enterprise were presented. With the continual growth of armaments and increase in shell power, however, the tendency to develop defence in depth, and to hold a front by fire power rather than man power became more and more marked. The continuous front line was replaced by weakly held forward observation posts, supported by positions situated well to the rear. By the close of 1917 it had become a recognized principle that the main centres of resistance should be sited beyond the range of hostile trench-mortars and incidentally that of underground attack. Further, the isolated front-line posts did not create for the

*See *Military Mining*, Chap. V.
†See *Military Mining*, Chap. VI.
‡See *Tunnellers*, Chap. XI.

execution and concealment of mining operations those favourable conditions which had been a feature of the solidly constructed forward defence systems of the earlier phase.

Thus the trend of evolution which position warfare had taken tended more and more to discount the value of mining as a means of assisting the infantry assault. But though the primary purpose for which mining troops had been organized gradually disappeared, the same factors which eventually led to an almost complete cessation of mining activity called for skilled underground work in another direction; the bulk of the tunnelling company personnel during the position warfare period of 1917-18 were employed in fulfilling the insistent and increasing demands for dugouts, subways and similar mined works.

On the First Army front alone over twenty miles of subways were constructed in 1917. Many of these works were miniature underground fortresses. Extensive dugout accommodation for the garrison, headquarters, signal and dressing stations, magazines, and stores led off the main thoroughfares; numerous gas-proofed and defensible entrances and exits were provided along their length; approaches led to machine-gun and trench-mortar emplacements at vantage points on the surface. In many instances trench tramways ran into the subways to facilitate the supply of ammunition and rations, and evacuate casualties; a small power station provided light throughout, and water was laid on. The garrisons were thus self-contained.

Not only was this class of work invaluable in facilitating reliefs and reducing the casualties of every-day trench life, but the subways by linking up dugout accommodation enabled the garrison to maintain a prolonged and concerted resistance when the surface defences had, during an attack, been overrun by the enemy. The defence of the Givenchy subways during the German offensive of 9th April, 1918, and following days, in which action the 251 Company took a prominent part, affords a classical example of the strength of works of this nature when garrisoned by determined men.*

IX. WORK OF TUNNELLING COMPANIES DURING THE LATTER STAGES OF THE WAR.

During the German offensives in the spring of 1918 tunnellers proved, if indeed further proof was necessary, that they were stubborn fighters above as well as below ground. The eight tunnelling companies on the Fifth Army front played their part manfully as infantry in numerous rearguard actions, during the retreat on the Somme. They also carried out many demolitions during this action. As the German effort gradually relaxed and the front again became more or less stabilized, tunnelling companies reverted to what had now become their normal role—the construction of deep dugouts and subways; some units, however, were employed on the preparation of extensive demolition schemes and the construction of reserve lines of defence, tasks for which they were well adapted.

The turn of the tide in the summer of 1918 called for the skill of the tunnellers in another direction; the rendering safe, or the removal, of the numerous land mines, traps and delay-action mines laid by the enemy. The Germans in their deliberate withdrawal on the Arras front early in 1917 had left behind many of these demoralizing devices and it was then realized that the tunneller, accustomed to delve in dark and dangerous places and an expert in explosives, was the man to deal with this menace. Scouting parties formed from tunnelling companies on this front had dealt with the situation on this occasion with signal success. When therefore, in 1918, a German withdrawal on a large scale appeared imminent, selected parties of tunnellers in all the armies were given a special course of instruction, based on previous experience, in the methods of investigating newly-won ground and the destruction of enemy traps, etc. As a result,

*See *Tunnellers*, Chap. XIII.

specially trained tunnellers accompanied advance guards of all formations during the victorious advance. Their task was to examine and pass as fit for occupation, dugouts, subways, buildings, etc., and any other locality in which enemy mines were likely to be laid. The work required steady nerves, keen observation, caution and ready deduction. The best proof of the efficiency of these detachments is the small number of casualties suffered by the British Army from these insidious devices. Some idea of the extent of the work can be gauged by the fact that in carrying out the task over two-and-a-half million pounds of explosive were removed or rendered harmless. The detection of cunningly concealed delay-action mines proved an exceptionally difficult matter and, when discovered, the extraction, from the heavy charge, of the fuze, often on the point of firing, was a delicate and highly dangerous operation. Considering the great risks that had necessarily to be taken, however, casualties among these tunnelling company detachments were surprisingly low.

Simultaneously with the provision of these forward detachments, tunnelling companies, in common with all available engineer units, were employed in the restoration of communications so extensively damaged by enemy action. In this new field of activity tunnelling companies did outstanding work. Though they possessed few skilled tradesmen they had the great advantage of being in a position to furnish a large force of men skilled in the use of pick and shovel and thus, unlike the majority of engineer units, did not have to rely to the same extent on working parties from other units. The comparatively liberal provision of mechanical transport in the establishment of these units was another asset in their favour. Many miles of roads were built or reinstated and 149 heavy and 38 light bridges constructed. The most notable engineering achievement was the construction of a 180-ft. span heavy bridge over the Canal du Nord by the New Zealand Tunnelling Company.

The great demand for miners at home after the Armistice resulted in tunnelling companies being among the first units to be disbanded. Prior to dispersion, however, they received a special message of appreciation of their work in the Great War from Sir Douglas Haig, in which he said: " They have earned the thanks of the whole army for their contribution to the defeat of the enemy. Their fighting spirit and technical efficiency has enhanced the reputation of the whole Corps of Royal Engineers, and of the Engineers of the Overseas Forces." The full text of this unique tribute will be found in the concluding chapter of *Tunnellers.*

X. Conclusion.

The history of the tunnelling companies in 1914-18 affords a fine example of the successful performance of one of the main roles of the Corps of Royal Engineers in a major war—the adaption of the engineering resources of the nation to military requirements. The outstanding success of these mining units, must however, in a very large degree be attributed to the excellence of the personnel.

The miner, whether from the metalliferous mines overseas or from the collieries of Great Britain, from which the majority of the rank and file were drawn, possesses qualities that go to make a first-class soldier. Inured from youth to the rigours and dangers of life in the pit, the miner withstood well the hardships of the trenches, which differed only in degree from those of his normal life. Moreover he was accustomed to obey the stringent regulations enforced for safety underground and was well schooled in team work; thus the yoke of military discipline fell lightly on his shoulders. Above all, just as the brotherhood of the sea forms a link between sailors, miners are animated by a deep sense of loyalty to their fellow underground workers, a bond which in a military environment is easily forged into a fine *esprit de corps*. The last words of Sapper William Hackett, V.C.* "I am a tunneller, I must look after my mate" is typical of the spirit of these men.

It is difficult to pay adequate tribute to the work of those who officered this fine body of men. Many of the officers in civil life were colliery officials of prominence in mining circles at home or in the Dominions. A very large number, however, were metalliferous mining engineers who had answered the call from all quarters of the globe "from China to Peru." They had had experience in running mining enterprises in remote districts where they had to fend and think for themselves—first-class training for the future R.E. officer. These officers, used to improvisation, were capable and ready to take on any engineering job above as well as below ground.

This enterprising spirit permeated all ranks, and towards the end of the war, when, as has been seen, mining work being no longer required, the tunnelling companies undertook other engineering tasks, the versatility of these units did much to enhance a reputation already gained underground. The tunnellers, organized as specialized R.E. units, not only carried out the task for which they were formed with conspicuous success, but also qualified as true sappers under Kipling's definition in that they were "men who do something all round."

THE TACOMA SUSPENSION BRIDGE.

By S. DENNIS, B.E., A.M.I.E. AUST.†

(Reprinted from *The Journal of the Institution of Engineers, Australia*, for July, 1942.)

INTRODUCTION.

THE failure of the bridge over the Tacoma Narrows at Puget Sound in the State of Washington, U.S.A., has created world-wide interest. Although the only casualties apart from the loss of the structure itself, were one dog and one motor car, the newspapers and technical press of U.S.A. have been full of details and theories, whereas the sinking of a ferry vessel with hundreds on board, of whom between 10 and 20 were drowned, was dismissed with a bare half-column. The reason is that the public has become accustomed to the solidity and security of such structures, especially in America where bridges of large span are more numerous than in all the rest of the world. A further reason for the publicity is due to the exhibition of films taken of the failure. This was possible as the failure was not sudden but the extraordinary movements continued for some days, and the tenacity of the structure under the conditions shown speaks well for the materials used, and leads to the opinion that the final collapse might have been prevented with a slightly more conservative design and the opportunity to stiffen the bridge as has been done with other bridges of similar type.

DESCRIPTION OF STRUCTURE.

The main span of 2,800 ft. is the third longest in the world, being exceeded only by that of 4,200 ft. at the Golden Gate, San Francisco, and 3,500 ft. of the George Washington Bridge over the Hudson River at New York. The side spans are 1,100 ft. each, and the total length of bridging is 5,939 ft. The clearance

*For an account of the circumstances under which this posthumous V.C. was awarded see *Tunnellers*, p. 166-7.

†This paper, No. 786, originated in the Sydney Division of The Institution, and was presented before a General Meeting of the Division and of its Civil Engineering Branch, on 9th October, 1941. The author is Bridge Engineer, Department of Main Roads, N.S.W.

for shipping is 196 ft., which compares with 170 ft. under Sydney Harbour Bridge. No provision was made for railway traffic, but a roadway 26 ft. wide to carry two lanes of traffic and two footways each 4 ft. 9 in. wide was provided. (See Fig. 1.) The loading adopted in the design was that of the A.A.S.H.O.,

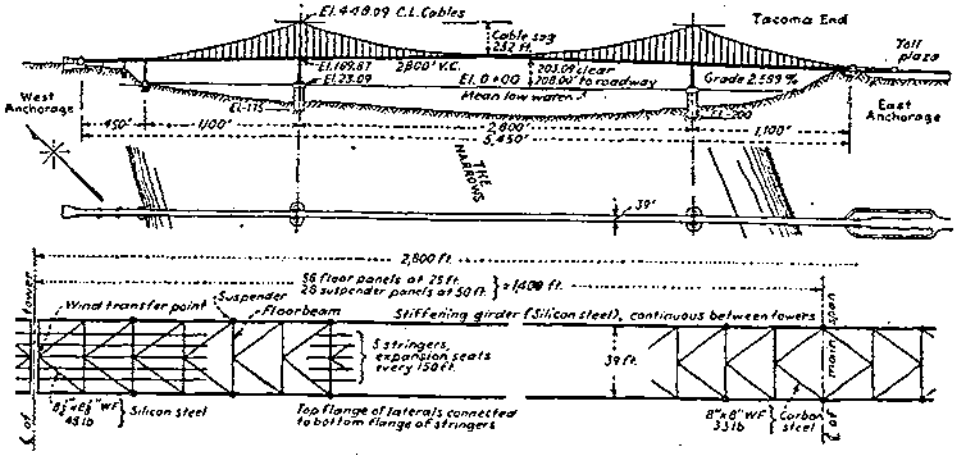


Fig. 1.—Showing Main Dimensions of Tacoma Bridge.

known as H.20, consisting of a 20-ton truck in each lane and a distributed load of 640 lb. per lineal foot of lane. The deck is of concrete 5½ in. thick on steel stringers and cross girders placed at about the centre of the stiffening girders and acting as the web of the horizontal girder, as shown in Fig. 2. The main piers were located in about 120 ft. depth of water and the deepest was founded at 224 ft. below low water. The bridge cost $6,400,000, and was built by contract for the State of Washington, subsidized by the Federal authorities, as it facili-

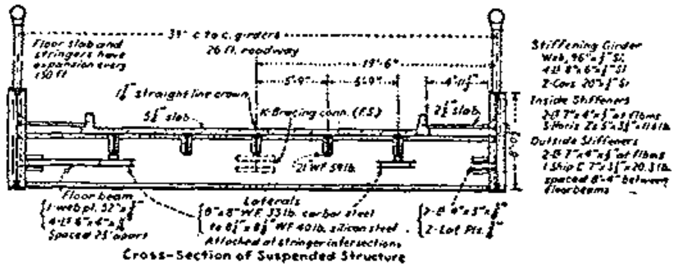


Fig. 2.

tates traffic to the Navy Yards in Puget Sound. Probably, if a greater sum had been available the traffic facilities would have been increased and the structure made heavier with a much better chance of survival, but the world would have been deprived of the results of the following investigations. Incidentally, the insurance companies who guaranteed the structure have agreed to pay $4,000,000 and it is now proposed to build a cantilever bridge with smaller main span, but to carry a railway in addition.

The towers carrying the cables are 420 ft. high and were bent 3 ft. shorewards during erection and 3 in. under full dead load, which compares with 12 ft. after the failure. These towers are of the type adopted for the more recent suspension bridges where the cables are fastened to the top instead of resting on rollers, and the varying loads on the cables are transmitted to the towers which bend. The vertical reaction on the towers was 4,800 tons. The cables are each 17 in. diameter and the sag is 232 ft. the ratio of span to sag being 12 : 1, which gives a high stress in the cable and corresponding stiffness. The stiffening girders, 39 ft. apart, are only 8ft. deep, of plate web construction stiffened by angles at mid-height. The ratio of span to depth of truss is 350, which is extraordinarily high and this, combined with the ratio of 72 to 1 for the span to width (also extraordinarily high), shows that the limit of flexibility of floor and reliance on stiffness of cables was reached. This combination is the most likely cause of the failure considered from the purely empirical view which usually governs the general proportions of structures.

SUSPENSION BRIDGE DESIGN.

The suspension type of construction has been employed for bridge purposes since earliest times. The use of woven twigs or fibre to form cables crossing streams or chasms is of unquestionable prehistoric origin, and the use of metal for bridges probably had its origin in suspension bridge construction, since iron chain bridges of the suspension type are known to have existed in China before the dawn of the Christian era. The first use of steel in bridge construction is reported to have been for the eye-bar chain cables of the Danube Canal Bridge, built in Austria in 1828. Since the beginning it has been recognized that the suspension type lent itself most suitably to long span construction and some of the crude chain structures built more than 2,000 years ago, are reported to have had spans of 200 feet or more.

Suspension bridges with load hanging from the cables were introduced by an American named Finley, and are designed on the assumption that the load is practically uniform along the horizontal line of the deck and the cables would then hang in a parabola. Live loads cause a departure from this assumption, but normally any variation is so small that they are amply damped out by the use of a stiffening truss or girder. The stresses in the cables then increase uniformly from centre to top of tower. For vertical static loads of the usual type, this is normally sufficient.

For wind loads the deck is generally fairly stiff, but if the ratio of span to width is greater than 20 to 1, the side deflections are considerable unless stiffening trusses, which give a large moment of inertia laterally, are used. The cradling of the cables or increase in distance at the towers over that at the centre, can only be effective to a slight degree in long spans. Even the George Washington Bridge with a ratio of 33 to 1 is very flexible horizontally, due to the absence of a stiffening truss until the second deck to carry railway loading is added.

The major problem, which defied satisfactory solution, was that of preventing undulations caused by the wind, and many early bridges failed in this manner. The common method of resisting such undulations was that of fastening guys or stays to the cable and anchoring these to the sides of the chasm or to the abutments. Many foot-bridges are built on this system and are stiffened in a horizontal direction by additional cables in a horizontal plane. It is of interest to note that, substantially, this same method has been recently employed in an attempt to prevent wind oscillation in the bridges constructed at Deer Isle and Thousand Islands.* Structures of this type were in early times frequently used for military purposes, and many such structures failed under the effect of dynamic forces created by marching troops. The idea for marching troops to break step when crossing a bridge, probably originated as a result of the use of such bridges for military purposes.

The suspended floor arrangement introduced a new element in the design of suspension bridges in that the floor, which was essentially separate from the cables, could be made comparatively stiff and resistant to change in form as an

*See *Engg. News Rec.*, 5th Dec., 1940.

independent structure. In fact, one of the features upon which Finley placed great stress, was the arrangement for distributing concentrated load over a great extent of the bridge and over the cable which then avoided sharp changes in direction and excessive deflection in one place, thereby aiding to divide it over many suspenders and stiffening the otherwise movable floor against change in shape.

Table I gives the governing dimensions of large recent long span bridges showing the very recent increase in flexibility.

Thus, even up to the present time engineers have focussed their attention almost entirely upon the idea of furnishing stiffness to limit change in gradient of the floor, and have been seemingly unmindful of the fact that in providing such stiffness they may also be producing resistance to undulations and the effects of unknown dynamic forces.

Bridges are flexible structures and the deflections under varying loads can be considerable without any serious consequence, unless they occur at regular intervals corresponding to the natural period of vibration of the structure or to some harmonic. Ordinary truss bridges which are generally stiff, have periods varying from 1/10 second for 40 ft. span to ½ second for 360 ft. span, as given in the report of the Bridge Stress Committee in England. For longer bridges the period is longer and for Tacoma Bridge was about 12 seconds. Rhythmic variations of this period are not likely to occur, but in a structure of uneven stiffness such as a suspension bridge with comparatively stiff towers, heavy cables, and very flexible floor, a minor harmonic could cause resonance.

Roebling was the first to use modern wire cables. His greatest bridge was the Brooklyn Bridge of 1,595 ft. span, built in 1883. This was a wide two-deck bridge and this provided adequate stiffening. On this bridge there was insufficient clearance below the deck for stays, so they were used from the tops of the towers. This is the first use of diagonal stays, and similar stays have been proposed to reinforce more recent light floor bridges. These stays, however, are stressed by live load, and their adjustment therefore becomes difficult, and they are not needed if a substantial stiffening truss is used.

New theories about stiffening trusses at this time led to some very heavy construction, an example of which is the Williamsburg Bridge, which has a stiffening truss 40 ft. deep.

The Manhattan bridge, built in 1909, was designed on the deflection theory which took into account the combined action of stiffening truss and cable in deflection, and the structure has been called the first truly modern suspension. A number of bridges were built about this time, and in all these the stiffening trusses were relatively light. The bridges were designed for heavy train loading, requiring a heavy floor system and heavy stiff cables, as well as increasing the width, as they carry roadways in addition, thus providing lateral stiffness.

As the motor era came in, relatively light constructions were all that were needed.

In general, no consideration was given to the possible effect of the floor and stiffening trusses in resisting undulation caused by wind or dynamic forces or, in fact, of the need for providing such resistance in a bridge. Complete attention appears to be focussed on the matter of vertical or horizontal deflection under known static forces. This probably accounts for the conclusions that stiffening trusses could be made shallower, in fact replaced by girders, and that the width to length ratios could be safely decreased for long span work.

No measure of torsional stiffness has, so far as we know, ever been applied to suspension bridges, nor is it apparent that the need for this form of resistance has ever been recognized. It may be observed that both the width to span and depth to span ratios are, however, approximate measures of torsional stiffness.

The general dimensions of 17 long span suspension bridges built since 1923

TABLE I

LONG SPAN SUSPENSION BRIDGES BUILT SINCE 1923.

Bridge.	Year built.	Span between towers. (ft.)	Length of side spans. (ft.)	Height of steel towers above masonry. (ft.)	Size of cable. (diameter).	Cable sag. (ft.)	Ratio, span to cable sag.	Depth of stiffening trusses or girders. (ft.)	Ratio, span to depth of stiffening truss or girder.	Width between cables or girders. (ft.)	Ratio, span to width.	Suspended weight per foot of span. (lb.)
Bear Mountain	1924	1,632	—	350	2 @ 18	—	—	Truss 30	55	55	30	—
Delaware	1926	1,750	751	343	2 @ 30	200	9	,, 28	63	89	20	26,000
Ambassador	1929	1,850	{972 817	363	2 @ 19¼	206	9	,, 22	84	67	28	—
Mid-Hudson	1930	1,500	750	280	2 @ 16¾	149	10	,, 20	75	42	36	8,800
Mt. Hope	1930	1,200	504	254	2 @ 11	120	10	,, 18	83	34	35	5,300
Geo. Washington*	1931	3,500	650	565	4 @ 36	325	11	None*	120*	106	33	26,035
St. John's	1931	1,207	430	285	2 @ 16¾	121	10	Truss 18	67	52	23	—
Maysville (Ky.)	1931	1,060	465	165	2 @ 13	—	—	,, 14	77	28	38	—
Ile d'Orleans	1935	1,059	417	{218 420	2 @ 10	112	9	,, 13	81	32	33	—
San Francisco, Oakland Bay	1936	2,310	1,160	464	2 @ 28¾	210*	11	,, 30	77	66	35	18,400
Triborough	1936	1,380	3,904	271	2 @ 20⅜	138	10	,, 20	69	98	14	19,160
Golden Gate	1937	4,200	1,125	690	2 @ 36½	470	9	,, 25	168	90	47	21,300
Lion's Gate (Vancouver)	1938	1,550	614	—	—	150	10.3	,, 15	103	40	39	—
Thousand Islands	1938	800	350	—	—	—	—	Girder 6	133	30½	26	3,200
Deer Island (Sedgwick)	1939	1,080	484	—	—	—	—	,, 6½	166	23½	47	2,400
Bronx-Whitestone	1939	2,300	735	363	2 @ 22	200	11.5	,, 11	209	74	31	10,940
Tacoma Narrows	1940	2,800	1,100	425	2 @ 17	232	12.1	,, 8	350	39	72	6,000
Mackinac Straits Bridge (Proposed)		{4,600 2,950	{1,600 1,050	— —	— —	— —	— —	— —	— —	{50 50	{92 59	— —
San Remo	1940	550	—	96	2 @	70	8	Truss 6	92	24½	22	900

*As now built, bridge has no stiffening truss. When lower deck is added, a 29 ft. deep truss will be built between decks.

are listed in Table I. Three of these structures, namely, Thousand Islands, Deer Isle, and Bronx-Whitestone bridges, have shown such tendency to oscillate as to require the installation of corrective devices; a fourth, the Tacoma Narrows Bridge, failed. Of the remaining thirteen bridges which, to date, have been successful; one, the George Washington, is completely unstiffened, but embodies very heavy cables, and a heavy floor; twelve of these bridges employ stiffening trusses, not girders; two bridges have stiffening trusses less than 1/84 of the span in depth, one using a ratio of 1/168 but with a large dead load, and the other a ratio of 1/103; only one bridge has a width less than 1/38 of the span and this, the Golden Gate, has a width-span ratio of 1/47. It is obvious from a consideration of this table that the trend in the last ten years has been towards increasing the sag ratio for the cables and elimination of stiffness, both vertical and lateral, for the suspended floor. In regard to such trend, it is of interest to note the controversy which existed more than 100 years ago between the French and English school of engineers, led by Navier, and the American group, led by Finley. Navier believed he could prevent greater displacements by using flat catenaries, and advocated perfectly movable floors and sag ratios of 1/12 to 1/15 for the cable; on the other hand, Finley and his American followers advocated stiff platforms with strong rigid railings to resist displacements, and used a sag ratio of 1/7 for the cable.

Out of the early failures developed the empirical laws of proportion which have governed all suspension bridge design to within the present decade. The danger which lies in arbitrarily tampering with these proportions is clearly shown by the performance of recent construction.

Failures of Suspension Bridges.

Many suspension bridges have failed due to weakness mainly in the cables and their anchorages, but Table II shows those which failed due to dynamic action.

TABLE II

SUSPENSION BRIDGE FAILURES DUE TO WIND OR DYNAMIC CAUSES.

Bridge	Location.	Span (ft.)	Year built.	Date of failure.	Length of life (Years.)	Reported cause of failure.
Dryburgh Abbey	Scotland	260	1817	1818	6*	Wind storm.
Union	England	449	1820	1821	6*	Blown down by wind.
Brighton Chain Pier	England	255	1823	1836	13	Oscillation caused by wind.
Menai Straits	Wales	580	1826	1839	13	Oscillation caused by wind.
Broughton	England	145	1829	1831	2	Marching troops.
Montrose	Scotland	432	1829	1838	9	Wind storm.
Nassau	Germany	245	1830	1834	4	Wind storm.
Roche-Bernard	France	641	1840	1852	12	Wind storm.
Wheeling	West Virginia	1,010	1849	1854	5	Violent wind, inadequate stiffening.
Lewiston	New York	1,041	1850	1864	14	Under wind when wind cables were removed.
Ostrau	Czechoslovakia	216	1851	1886	35	Dynamic effect of troop cavalry.
Steubenville	Ohio	700	1905	1923	18	Twisting under one-sided load: distortion being favoured by the weak lateral and sway system.
Tacoma Narrows	Washington	2,800	1940	1940	4*	Oscillation due to wind.

*Months.

One of the early suspension bridge failures resulting from wind action, of which there is authentic record, was that of the Brighton Chain Pier (England) which failed in a gale on 30th November, 1836. In an account written by Lieut.-Colonel Reid and published in Vol. 1 of the *Professional Papers* of the Corps of Royal Engineers (Great Britain) it is stated:—

"At last the railing on the east side was seen to be breaking away, falling into the sea; and immediately the undulations increased.

Had the roadway been stiffened, either by a good trussed railing, or otherwise, it probably would have withstood this storm. From its oscillating sideways as well as undulating along its length, it seems to require stiffening against both these motions."

It may be interesting to observe from the sketch of this failure made by Lieut.-Colonel Reid in 1836, that the behaviour exhibits a remarkable similarity to that of the Tacoma Bridge more than one hundred years later.

The Montrose Bridge in Scotland, built in 1829, failed in 1838 during a hurricane. An undulating motion was observed during this storm and it was stated that the motion was greatest midway between the centre of the span and the towers.

The next record of the Menai Straits Bridge is more complete. The bridge was opened in 1826, had a span of 580 ft. and very little stiffening in the handrail. This bridge undulated in an almost identical manner to the Tacoma Bridge, three times. Damage was caused but the bridge did not fail.

In 1849 Charles Ellet built a 1,010 ft. suspension bridge over the Ohio River at Wheeling. In 1854 the floor of the bridge was completely destroyed by a hurricane, and here again the description of the failure is almost identical with that at Tacoma.

A suspension bridge was also built over the Niagara River at Lewiston, in 1850. Guys, such as Roebling had employed, were used to hold this bridge against wind action. However, an ice jam in the gorge led to these being temporarily removed in 1864, and the structure failed by oscillations in a windstorm a few weeks later. Another wind failure at Niagara was that of the Niagara-Clifton suspension bridge which had a span of 1,260 ft. and was originally only 10 ft. wide, but was later widened to 17 ft.; this bridge failed in a windstorm which reached 74 m.p.h., and is said by an eye-witness to have tilted almost up on its edge.

Other Evidences of Effects of Dynamic Forces.

The George Washington Bridge, built in 1931, was designed for two decks, with trains on the lower deck. The lower deck was not built and it was found that there was no need to build the stiffening truss as the cables were so stiff that no further stiffening was required. Following this experience, engineers began to design narrow light highway suspensions with relatively shallow girders instead of stiffening trusses. As far as the distribution of vertical loads was concerned, these girders were sufficient, but it was appreciated that lateral forces would produce large deflections. The problem, however, was only considered as one of static loading.

In the summer of 1938 a supposedly new phenomenon was observed at the Golden Gate Bridge. A 78 m.p.h. lateral wind was blowing which caused a lateral deflection of 8 ft. but it also caused a wave of undulation to pass over the bridge, sufficient to permit the double suspender ropes to slap against each other. This bridge has a stiffening truss and movement was very small.

The same phenomenon occurred at the Thousand Islands suspension and the Deer Isle Bridge in Maine. Various devices were used with success to damp the undulations. Diagonal cables between floor and cables, and horizontal friction dampers at the towers were used.

New York's Whitestone Bridge of 1939, noted for its slender light floor and stiffening plate girders, exhibited a tendency to undulate, and it has not only been braced but also most carefully watched.

The Tacoma Bridge Failure.

Construction was completed in July, 1940, and from the outset the structure showed a disturbing tendency to oscillate. A similar tendency had been noted in Whitestone Bridge, New York, which is of a similar type, but in that case the movement amounted to only a few inches, whereas at Tacoma the vertical waves reached an amplitude of over 4 ft. in moderate breezes.

Before the bridge was finished the tendency to oscillate was noticed and a scale model one hundredth the size, *i.e.*, 54 ft. long, was made and tested by the University of Washington. Electro-magnets were fitted so as to apply horizontal and vertical forces simulating the effects of wind pressure. It was found that the behaviour of the actual bridge could be duplicated with great accuracy and various corrective devices were tried. Ten different wave periods were observed on the model and also on the bridge, the most frequently observed being the 12 sec. one which was the same as the period of the towers.

The bridge itself oscillated in a number of different ways with differing periods, but the most frequently observed period was one of 12 sec. when the maximum amplitude occurred at the quarter points, little movement being observed at the centre. Vertical wave motions were not proportional to wind velocity. Sometimes considerable waves were produced by wind as low as 4 m.p.h. and again there would be no waves in winds as high as 32 m.p.h. Tie-down cables with

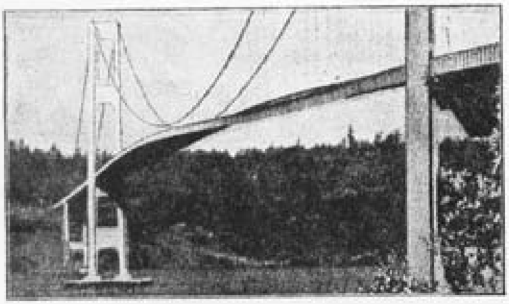


Fig. 3.—Showing Rolling, just prior to Failure.

stress-limiting links had been put in the side span 300 ft. out from the anchorage. Similar tie-downs were used at Northbridge (Sydney) in the side spans when strengthened for tramways in 1913.

Prior to 7th November, 1940, such vertical waves as had occurred had never got out of step on opposite sides of the bridge and no damage was done. On that date, however, a wind of 42 m.p.h. was blowing; higher winds had been experienced without damage, but on this occasion the vertical wave motion developed a phase difference between opposite sides of the bridge giving the deck a cumulative rocking or side to side rolling motion. (See Fig. 3.)

The deck is reported as having tilted from side to side more than 45°, and the edges of the deck had an up and down movement of 28 ft. with an acceleration at times greater than that of gravity.

Failure appeared to begin at mid-span with buckling of the stiffening girders, although lateral bracing may have gone first; as the violent whipping continued, many of the vertical suspension ropes were broken and sections of the flooring fell out successively several hundreds of feet at a time, until only short lengths remained projecting from the towers. Ropes had previously been fastened from the side spans to anchors and although some of these had been broken a few weeks before, it is thought that the remainder saved the side spans and possibly further damage to the towers. When the main span collapsed the removal of its load allowed the side spans to sag some 30 ft. buckling the stiffening girders

The Tacoma suspension bridge, fig 3 - page 49

and deforming the steel framework supporting the roadways. The unbalanced pull of the cables carried the tops of the towers 12 ft. towards the banks, buckling some of the plates and angles of the tower steelwork at the base. The piers themselves were undamaged, and it is stated that the cables show no evidence of having moved in their saddles. Fig. 4 shows a 600 ft. length of the floor system about to plunge into the Narrows.

In the Whitestone Bridge, short inclined rope ties were placed between mid-points of the main cables and the top flanges of the stiffening girders, to hold the bridge deck from moving longitudinally with respect to the cable. Friction brakes were also placed at the connection of the deck to the towers so as to damp any longitudinal movement. These provisions materially reduced the vertical oscillations. After the model tests, a similar arrangement was proposed for Tacoma, but nature got in first, and the bridge failed before they could be

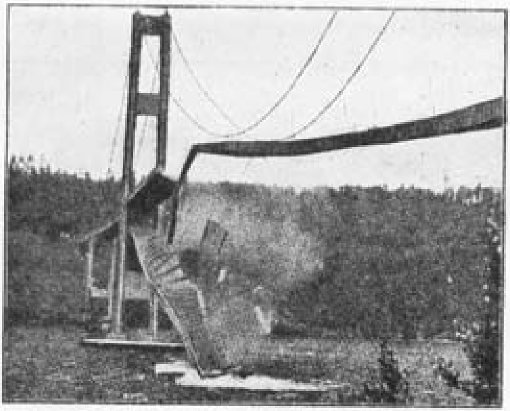


FIG. 4.—Showing Floor System Inverted, about to plunge into the Narrows.

applied. At Tacoma, one control method actually applied after proving effective on the model, was to tie down a point in each side span to the ground below. Such tie was provided on the bridge in the form of a $1\frac{7}{16}$ in. cable extending from the deck to 50 cu. yd. concrete anchors on the ground below. Diagonal ties from the tops of the towers to the stiffening girders, were considered but not tried.

The most favoured theory of the cause of collapse is aerodynamic instability of the bridge deck. Other theories are :—

(1) Insufficient lateral support of the compression flange of the stiffening plate girder. In this connection, it might be noted that there were no knee braces from cross girders to the top flange of the stiffening girder ; also, there were no vertical stiffeners on the inside of the web.

(2) That the stiffening member was a plate girder and not a truss. In so far as a truss would probably be deeper and therefore stiffer, this may be a contributing cause ; also, a plate girder would probably offer more wind resistance than the truss.

(3) That rhythmic gusts of wind of the same frequency as the natural period

The Tacoma suspension bridge, fig 4 - page 50

of the bridge, rocked the bridge with gradually accumulating motion until it failed.

However, the likelihood of gusts occurring at the exact times required to give an accumulating motion is very remote.

The most likely theory is aerodynamic instability of the deck combined with a lack of stiffness in the deck structure and an inherent tendency of the bridge to oscillate.

A theory proposed by Dr. Von Karman is that the deck fluttered in a similar manner to an aeroplane wing at a certain critical flying speed. The theory is that when the deck deflects sideways under wind, it tilts slightly, and then a horizontal wind will produce a lifting force which will tend to increase the angle. As the angle increases the lift increases, until the maximum lift is obtained, after which the lift decreases and the restraining forces make the bridge fall back and tilt the opposite way, and the process is repeated. Dr. Von Karman worked out from first principles the critical wind velocity for the Tacoma Bridge and obtained a fairly close value to the actual wind velocity observed at the time of failure.

It has been pointed out that the above theory does not account for the parallel undulating motion observed before the date of failure, when no twisting was experienced, and it has been suggested that galloping or wind eddy vibration, as well as flutter, may have contributed.

Galloping has been discussed in detail in engineering literature, especially with regard to transmission lines. This galloping does not ordinarily occur on a round wire, but has been observed on wires coated with sleet to a vertically elongated section. Galloping of wire spans has occurred with vertical motions up to 20 ft.

The conditions of galloping may be simulated on a model, wherein a section of an I beam elastically supported, is placed in the horizontal airstream of an electric fan.

A similarly supported beam of half-round section proved exceedingly unstable when its flat side faced the wind but refused to bounce when its convex side was to windward. The I beam section was completely stabilized by attaching a thin cardboard windbreak to the windward face of the beam; even when given an impulse, the beam quickly came to rest. Attached to the leeward side of the beam, the windbreak had very little effect.

A second possibility, wind eddy vibration, has been observed on transmission wires and has been the frequent cause of fatigue failures. Unlike galloping, this wind eddy vibration has a frequency principally dependent upon the wind velocity and the use of cross-section of vibrating member; the amplitude is, of course, accentuated when the forcing frequency corresponds to a natural frequency of the system. When a cylindrical beam was tested, it was found to be stable except at one critical velocity. The equation for such vibration is—

$$f=0.2 \quad \left(\frac{V}{D}\right)$$

when f is the vibration frequency, V the wind velocity, and D the diameter of the section.

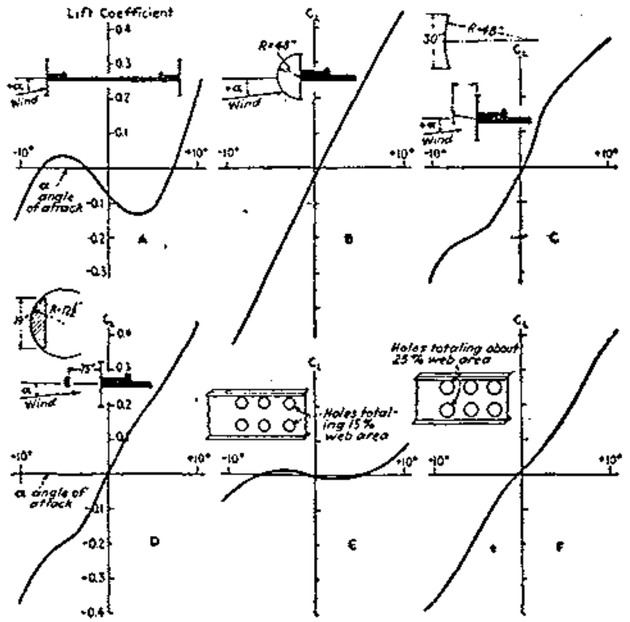
For the 20 cycle vibration observed at Tacoma, and using 8 ft. for D, V becomes 9 m.p.h. which is considerably less than the actual velocity, but the effective D may be considerably greater than the girder depth. This type of vibration might account for the fact that the bridge vibrated with different frequencies on different days.

Violent sidewise rolling was noted on 7th November, which is similar to flutter. Such rolling is ordinarily associated with a simultaneous transverse vibration of the member where the natural frequencies of rolling and transverse vibration are of the same order.

Photographs taken during failure appear to indicate that a rolling vibration was occurring simultaneously with a vertical bounce, having nodes only at the centre and ends of the span. In vibrating systems having several possible nodes of vibration, a vibration beginning in one of these nodes may develop into other nodes. Accordingly, either galloping or wind eddy vibration could very well provide an initial vibration from which rolling or flutter might develop. Flutter having once begun, high winds could readily amplify it to violent proportions.

For aerodynamic test, a 1 in 20 model of a section of the deck 160 ft. long, was made and tested in a wind tunnel. For a 45 m.p.h. wind, the formula developed gives an insignificant loading of no consequence in a rigid, as distinct from a suspended, type of structure.

Danger lies in aerodynamic instability, which was found to exist in this structure only with wind in or very close to a horizontal direction, namely, through the angle from 2½ to + 4½°. In an aerodynamically unstable structure,



Aerodynamic instability of the bridge deck was revealed by wind-tunnel tests on a model. The six curves show lift coefficient, plotted on angle of attack of the wind, for the deck as built and five modifications. Downward slope of the lift curve spells danger.

A. Deck as built. B. Deck with semicircular fairing. C. Deck shielded by 30-in. vane. D. Deck shielded by 19-in. vane. E. Girder perforated. F. Larger perforations.

Note that angles are positive when wind acts at an upward angle to the deck, or when in horizontal wind the leading edge of the deck is raised. Angles are negative when the wind blows from above the horizontal, or when in horizontal wind the leading edge of the deck is depressed.

FIG. 5.

the change in vertical wind component with angle of attack is subject to reversal, and the resulting action may build up vertical wave motion whose cumulative possibilities are very great. See Fig. 5.

Wind tunnel tests on the model were all made with wind normal to the bridge centre line; other angles were not possible with the equipment available. On the day of the collapse of the bridge there was a quartering wind. This may have had some bearing on the unusually severe effect, and also on the fact that the same wind velocity has been observed to have different effects on different days.

When aerodynamic instability of the floor system, as built, had thus been discovered, attention was immediately turned to modifications that would improve its characteristics. Changes of two kinds were made on the model; (1) the use of some form of fairing or deflector vane attached in front of the stiffening girders, and (2) making holes in the webs of the girders to allow wind to pass through. The desired stability could be obtained, it was found, in either of these two ways, with relative degrees of effectiveness according to the shape and position of the deflector vane and the size and location of the holes. The scope of the tests on vanes ranged from deflectors of small radius up to a full fairing, presumably of steel plates, from top to bottom flange of the stiffening girders.

Small wind deflectors had to be farther from the girders than did those of a large size. Holes near the top, near the bottom, or in the middle of the girders were not nearly as effective as a combination of holes both top and bottom. Relative merits of different arrangements are shown in the lift coefficient curves in Fig. 5.

Although the holes gave satisfactory characteristics, it was believed that they would cost more and would mar the appearance more than a small curved plate that could be set in a position where it would not be visible from cars crossing the bridge. The deflector vane, that had characteristics best suited to a practical solution of this problem, gave a satisfactory curve; preliminary steps toward putting such a vane on to the bridge were being taken on the day of the collapse. As designed, the vane itself was to be made of wood with a chord width of 19 in. and curved face of 12½ in. radius, attached 80 in. out from the web by bracket angles, as in *D* of Fig. 5.

Conclusion.

Thus, history has been repeating itself, although this fact has apparently not been known even to engineers who have made a speciality of this type of construction. Increased stiffness against wind is needed. This can be provided by heavier deck or stiffening girders. It is possible that if the aerodynamic characteristics of the deck had been altered, the bridge would have been entirely satisfactory.

If long span bridges are to be built, as of course they must, considerations of economy demand that they be patterned to fit accurately their particular need. In order to accomplish this, the designer must be in possession of all the facts and conditions which relate to the behaviour of such structures. The evaluation of the forces which may act on the structure must be complete and the dynamic behaviour must be taken fully into account. There has been a lamentable lag on the part of structural engineers to apply sound aerodynamic principles to structures exposed to the action of the wind. The magnitude and nature of wind force acquires great importance on very large structures, yet the specifications used at present take no account of the size of the structure nor, in fact, do other than offer crude approximation of the true effects.

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Illustrations.

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Engineering News Record—Figs. 1, 2, 3, and 5.

Roads and Streets—Fig. 4.

THE EDUCATION OF THE MILITARY ENGINEER.

By LIEUT.-COLONEL D. PORTWAY, T.D., R.E.

AN article by General Davidson in *The Royal Engineers Journal* of September, 1942, dealing with collaboration between Military and Civil Engineers, draws attention to the peace-time training of the regular Sapper officer. It is a subject that is much discussed in time of peace wherever R.E. officers, whether senior or junior, are gathered together and there is very naturally wide and altogether healthy divergence of opinions.

Few officers will now doubt the wisdom of the step taken after the 1914-18 war when all Regular R.E. officers included the University training of a Civil Engineer in their ordinary course of study. This has helped to bridge the gap between the Civil and the Military Engineer—a gap whose width and depth is testified by the very name of Civil Engineer, which was adopted in flat contradistinction to that of Military Engineer. It has enabled the peace-time military engineering body to take its place with full success as the spearhead of the Army's engineering effort in a world war—so successfully indeed that few, other than regular officers, are required in the higher operational direction of military engineering.

Nevertheless, many thoughtful officers feel that all was not well with the system of Sapper officer training that existed up to 1939 and it is surely the time during and not after a great war to formulate ideas as to the post-war system that is desirable. The actual policy is of course for the higher command to decide but the opinion of more junior officers, and especially those who are in close touch with current education, may be apposite.

It is here assumed and it *is* an admitted assumption, that the existing practice of the British, and incidentally of the American Army, will be continued, in which all officers of the Engineer branch are given an engineering training and the men are qualified tradesmen. A vigilant Treasury has always looked askance at the increased cost of Sapper personnel in comparison with that of the other arms; they are likely to be more than interested in the outstanding success of the German Engineer Corps, in which officers and men are what we should call pioneers with no comprehensive engineer tradesman training. That corps has to their credit some stirring feats of arms, a conspicuous example of which was the capture of Fort Eben Emael by a single Engineer battalion aided by a detachment of parachutists on May 11th, 1940. This fortress, reckoned the strongest in Europe, was held by a picked regular garrison of 1,400 Belgian officers and men; it stood on a bluff 200 feet above the Albert Canal, which it was designed to defend and it was reckoned to be almost impregnable. Yet it was captured only 36 hours after the outbreak of war by a relatively weak force. It is a striking illustration of what can be done by thoroughly trained personnel actuated by a violently offensive spirit and with adequate equipment, careful reconnaissance, thorough planning and, above all, precise co-ordination.

There are certain fundamentals that must never be forgotten in the education of *all* Engineers whether military, civil, mechanical or electrical. It is essential that the engineering student should have a scientific outlook and should realize that scientific method is a mode of approach to the study of *any* field of human experience. This is a time when both scientists and engineers are claiming, and rightly claiming, a larger share in the work of the world, and are invading fields of activity that were long regarded as outside their competence. This was due in part to the restricted limits within which the technologist was allowed to work and which was reflected in his narrow and prescribed education—or rather lack of education. All this contributed to the undoubted fact that no solution has yet been found to so many problems that industrialism has brought in its train—such anomalies for example as the widespread distress and social retrogression brought about by the increased power of production and by the expanding economic unity due to mechanization and scientific discovery.

We have long abandoned the idea that scientific and literary studies are in any way antagonistic but the young engineer was frequently required to specialize at so early a stage that he was unable to receive that broad and liberal education which his literary brother enjoyed. This early specialization must be avoided at all costs so that the engineering student can attain the wide reading in the humanities that is so desirable. We must never forget the truth that was enunciated by Arnold of Rugby, that it is not knowledge but the means of gaining knowledge that the schoolmaster should teach.

We are at last realizing that the engineer must be not only a technician but something of an artist, possessing a sense of style and some æsthetic appreciation. These traits will be wanted above all in the post-war reconstruction. Imagination and the power of looking ahead are the qualities that are wanted here—as indeed in the rough and ready war-time training of the young sapper officer. Good taste and beauty of form are not easily cultivated by those who have concentrated entirely on the material and technical aspects of their work. It is so easy for the young engineer to be so weighed down by the narrow and deadening load of routine duties as to lose all vision and initiative.

While still at school the budding engineering student should learn the lesson that Sanderson of Oundle was one of the first to teach—the value in education of practical work and the importance of the team spirit, not only on the playing field but also in the workshop. " Don't learn to do," said Samuel Butler, " but learn in doing." A boy's early lessons in handicraft can best be acquired in making communal articles with tools forged and tempered in the school workshops. Such simple engineering work as mixing concrete can well be taught, for example, in the construction of reinforced-concrete fencing posts in the school playing fields. At this stage a boy wants to get away from one of the greatest evils in education—the teaching of snippets in any subject and the division of subjects into water-tight compartments. He will be far more interested in mathematics, for example, when he finds how much it is required in his science, in his geography and in simple workshop calculations.

There is nothing new in any of this and educational experts, from the President of the Board of Education downwards, are full of proposals on these lines in the post-war reconstruction. But so many of such proposals seem designed to turn the boy into a regimented and sealed-pattern type. No encouragement to individuality is given and few realize how important it is to make the most of any latent capacity possessed by a boy in some particular direction. It is difficult to avoid a good deal of such regimentation when the schoolboy graduates into the cadet at a Military College but even here it is possible to allow a good deal of individuality and much of the improvement in the training at the Royal Military Academy in recent years is due to an appreciation of this fact.

It is when the stage is reached for the specific training of the Military Engineer that the more controversial problems arise and the present course, interspersed over a period of four years between the S.M.E. and the University, is admittedly by no means ideal.

Many officers feel that the course at the University itself is too academic and too mathematical for some at any rate of the Sapper officers. There is little doubt that for a student of really first-rate ability the mathematical character of the Engineering Tripos as at present arranged is admirable, and not only presents no serious difficulty but is both stimulating to the mind and provides a suitable approach to the more practical problems. For such a student a rational approach along the lines of mathematical analysis is far more satisfying than the empirical formula which constitutes the alternative. Some Sapper officers of this category have told the writer of this article that they have found bits and pieces of the formidable and mathematically fearsome " B " subjects of direct use to them in surprisingly diverse directions. But this applies to the relatively few, and many students, whose mathematical ability is so limited that they only scrape through the Qualifying Examination in Mathematics and Mechanics with difficulty, are unable to see the wood for trees. They wallow in a Mathematical morass and are unable to take advantage of the mathematical approach to the various subjects. For this type the greatest value that is obtained from the University is from the human contacts that are gained in so many directions rather than in the technical attainments that have been acquired. For such students a simpler course—available at Cambridge in the Engineering studies course—would seem far more suitable and apposite. It would allow for some time to be spent in such important subjects as geology, works economics and the like. As this course fulfils the theoretical requirements of the great Engineering Institutions it would seem merely false pride to insist that the weaker vessel should undertake the Tripos. In any case it is more than likely that in the post-war reconstruction at Cambridge there will be radical changes in the Engineering Tripos itself—for many years the feeling in favour of a two-part Tripos has been vocal among many resident graduates.

It is *after* the four years at the S.M.E. and the University that the greatest improvements in the training of the Military Engineer would seem possible. The present practice is for the great majority of officers to be posted straight to units so that there is little opportunity for further technical training. It is well known that in the case of the civilian engineer, whether civil, mechanical or electrical, the most valuable part of the training comes at the end when he undergoes his practical experience. It is then that he gains some real insight into the practical direction of work as well as learning a good deal about modern methods of construction. At present most Sapper officers are denied the opportunity for this most essential part of an engineer's training.

It is true that many Sapper officers do a spell of duty as a garrison engineer but this type of work is more often than not trivial and superficial, especially under peace conditions when works expenditure is always so severely limited. Indeed it is increasingly open to doubt whether this should be considered as part of the normal work of the Royal Engineer officer. The chief point in its favour is that it does give him some experience in costing and an engineer has been defined as a man who can do for a pound what any fool can do for two! It is also true that a small percentage of officers undergo a good deal of further training of a civilian type. A few officers who will devote much of their future activity to Transportation are attached to railways and others are allowed to work with Civil Engineers or with contractors. But only a small percentage of the total officer strength of the Corps does this.

It is suggested that *all* Sapper regular officers should qualify as practical engineers and in very diverse directions. This would to some extent do away with the present ideal wherein the sapper officer is considered a Jack of all trades—the second part of the aphorism need not be quoted—but under modern conditions this ideal is becoming more and more impossible. The formation of the new Corps of Royal Electrical and Mechanical Engineers reflects this tendency and will give the expert Mechanical Engineer a greater measure of control over the Army's many mechanical problems. It will be argued that the Treasury would not allow a further two years of training but there is little doubt that the Institution of Civil Engineers would allow at least 6 months for the practical training—workshops, survey, etc.—at the S.M.E. and the other Institutions would surely follow suit. Before the 1914-18 war, when 3 years were required for this practical training and one year was insisted on by the Corps for R.E. training of the officers of the R.E. Special Reserve (now Supplementary Reserve), this year was allowed by the Institution of Civil Engineers to count against the three years' practical work; this valuable concession allowed a considerable reserve of trained officers for the Corps to be built up for the Expeditionary Force in 1914, their training being incidentally, by reason of this whole year with the Corps, far more complete than was possible in the case of the Supplementary Reserve officer mobilized in 1939.

The Corps would thus have a body of officers any one of whom would be qualified in one of the numerous branches of engineering in the fullest sense of the term and the value of this to an Army that is becoming more mechanized and more scientifically-minded every day is beyond question. It would be another step towards the ideal of a unified technical control of *all* engineering matters in the Army. But all this by itself would be of only limited value unless further opportunity were afforded for really practical work in the Corps under peacetime conditions. The value to the American Corps of Engineers of their experience gained in the construction of the Panama Canal and cognate tasks such as the trunk road now being constructed to Fairbanks in Alaska must be immense and it would be of great value if British Sapper units in peace-time were allowed to undertake work of national importance. After the war there will be important reconstruction work to be carried out for many years but quite apart from this there is plenty of work of immeasurable value to the nation that demands consideration. The harnessing of the River Severn on the lines of what has already been done in the case of the Shannon is an obvious example and so is the reclamation of the Wash. In Scotland the Highland hydro-electric schemes await fulfilment and a widened Caledonian canal would play an important part in the national transportation system both in peace and war, as would the resuscitation of hundreds of miles of derelict canals in England. It is surprising how little military engineers have been allowed to be used even when considerations of the utmost urgency were in question. A very few years ago the sea broke through the Norfolk Coast causing widespread flooding and there was threat of further disaster over a wide area. A few field companies would have been of the utmost value in the construction of immediate repairs and it would have been admirable training, but nothing of the kind was done and the necessary work was carried out slowly and at a risk of further misfortunes with such resources as the local Catchment Board could provide.

No doubt the Trade Unions would look askance at the use of military units for such work but we have surely learned enough as a result of the present war to appreciate that sectional interests must not be allowed to interfere with courses of action so desirable in the national interest.

Finally, and whatever the precise type of training that the Engineer arm receives for its special duties we must never forget that the *First* duty of the sapper is as a fighting soldier, using combat engineering in getting the Army forward in battle. Whether the obstacle is a crater to be filled in, a minefield to be destroyed, a river to be bridged or a fortification to be reduced, the field squadron and the field company must be the very spearhead of the attack. The problem for the British as compared with the German is complicated by the need to train the British sapper for working under all sorts of conditions, much of the work varying widely from the *Blitzkrieg* duties with which the German Engineer Corps is mainly concerned. Certainly the only solution—quite apart from the precise system of training—is for the British sapper, both officer and man, to be absolutely first-rate, physically, mentally and technically. Only a *corps d'élite* can combine the skill of the technician with the fighting qualities of the special-service soldier. It can be well appreciated that the successful performance of such varied duties with speed and efficiency under present-day conditions calls for such qualities of skill and endurance as will yet further enhance the proud reputation that has always been enjoyed by the Corps of Royal Engineers.

CAISSON DISEASE.

By CAPTAIN W. D. ALLAN, *Royal Army Medical Corps.*

(*Reprinted by kind permission from The Journal of the Royal Army Medical Corps.*)

AT the present time when the use of compressed air by the R.E. may at any time be necessary and any Medical Officer may find himself faced with the task of treating cases of Caisson or Compressed Air Disease, I thought that a brief statement of my experiences in the prevention and treatment of this condition might be of more than usual interest.

To most Medical Officers the condition is merely a name, as it is a disease seldom met with, occurring only during the laying of foundations, tunnelling operations, etc., and the contractors conducting these operations often have their own Medical Officer to superintend. Naval Surgeons are, of course, more familiar with the condition, as it occurs during diving exercises.

Tunnelling is a fairly simple process when it is through rock, chalk or any material which will not "fall-in," but when the Engineer has to drive his tunnel straight on, through running water and sand, he is faced with a very different and most difficult problem. He is then forced to have recourse to the use of "compressed air," in order to hold the walls of his excavation together, until such time as his workmen can construct the necessary retaining walls. This, of course, makes the construction proceed very slowly and the danger of collapse has to be constantly guarded against as it means loss of life as well as loss of time and money.

I would here pay tribute to my ex-employers, Sir Robert McAlpine and Sons, and to their staff, as they spared neither time nor money in order to ensure the maximum of safety for all their employees engaged in the construction of this particular sewer. The type of ground encountered was most difficult as a great deal of running sand and water was met with.

In order that one may appreciate the causation and symptoms of the disease, a brief description of the apparatus used by the Engineers and the expense and labour involved in its construction would seem to be expedient. Although I know full well that Editors in general do not look kindly upon the incorporation of diagrams in any article, I would crave the indulgence of ours in particular for his permission to insert a simple one.

It might be of interest at this point to give some idea of one's sensations on being compressed and decompressed, as this may be of assistance to an M.O. or to an Engineer in his choosing of suitable personnel. The "nervous type," no matter how physically fit he may be, is quite unsuitable for this work.

On entering the air-lock, where one has usually to crouch in discomfort, with the doors closed as shown in the diagram, one's first sensation is one of fear or as nearly that as not to matter. Compressed air is now allowed to enter steadily into the chamber, slowly at first but later increasing in volume until the desired pressure is reached. On being compressed one should chew a sweet which causes salivation and consequent swallowing, or forcibly blow one's nose, as doing this helps to allow the air to enter the Eustachian tubes and so aids the equalization of pressure on both sides of the tympanic membrane. Until this takes place one has a very painful and boring sensation in the ears, but afterwards one is quite comfortable. On being decompressed, which never should be hurried, the feeling is simply one of chilliness, varying in degree with the length of time one has been confined in the compressed area.

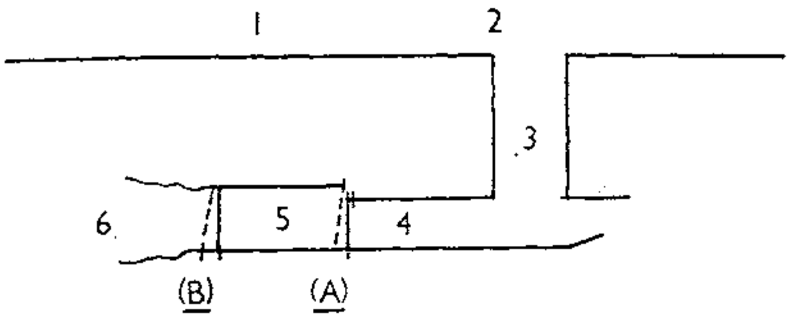
In choosing men for this work, I have found it sound not to be guided too much by the ordinary standards of physical fitness, as a raised blood-pressure, some slight cardiac involvements, etc., are of no consequence as long as they are within reasonable limits and the workman has the proper temperament. It is well known to Contractors that certain men will always follow dangerous employment, because of the very high rate of wages, and these men if reasonably fit can always be satisfactorily employed, as they have no fear, being familiar with the type of work. This absence of fear is a very important factor. Men suffering from bronchitis, head-colds, and ear conditions are always unsuitable, while varicose veins certainly predispose to attacks of " bends " as the condition is called by the men.

Causation of Caisson Disease.—The real cause is always too rapid decompression.

Exciting Causes.—(1) Overlong working hours. (2) Very high pressure of compressed air sometimes required. (3) Amount of danger involved (this is an important factor even with experienced men). (4) Type of soil being worked.

The mechanism of the condition is simply the fact that gases dissolve in the blood according to the pressure, so that when one is compressed the nitrogen is forced in from the tissues and is dissolved in the blood. It is estimated that at a pressure of 20 pounds per square inch the blood contains four times its normal nitrogen. The 20 pounds is, of course, 20 plus the normal atmospheric pressure of roughly 15.

When one is decompressed slowly, it gives time for the nitrogen to be reabsorbed by the tissues, but when decompression is too fast the tissues cannot absorb the gas quickly enough and it therefore circulates in the blood-stream as very small bubbles of nitrogen, really gas emboli. The best example of the action is seen in the opening of a bottle of soda water. When the stopper is in



1, Ground level. 2, Entrance to shaft. 3, Shaft of varying depth, which may or may not require to be air-locked. 4, Completed portion of tunnel. 5, Steel air-lock. (Note that door (A) opens inwards while door (B) opens outwards.) 6, Working face. (Here pressure has to be kept sufficiently high to prevent walls from collapsing.) The pressure in the air-lock must be the same as that in the working-face before door (B) can be opened, and of the same pressure as that in the shaft before door (A) can be opened. This means that all personnel as well as all materials must be compressed on entering lock on way to working-face, and decompressed before leaving lock to proceed to the surface.

situ, the contents of the bottle are still, but immediately the stopper is removed and the pressure relieved brisk effervescence occurs. Sooner or later one or more of the emboli will come to a small vessel—too small to allow it to pass—and the result is an attack of the " bends " or Caisson disease.

It cannot be too strongly stressed that one, when fixing length of working hours and the decompression times, should err on the safe side. When however one gets to know his men, etc., he may if the occasion arises take a chance without much danger. Personally I have repeatedly been decompressed in a fraction of the proper time with little bad effect but, of course, I had only been compressed long enough to attend to my medical duties.

When men are working in pressures of under 20 pounds they can safely be allowed to work a six to eight hours' shift and require a decompression period of only about forty to fifty minutes in the air-lock before surfacing. When however, the working pressure is over 20 pounds the working hours must be shortened and the period of decompression lengthened and, even when all precautions are taken, casualties will result.

This 20 pounds "danger point" perhaps sounds peculiar, but I have repeatedly noted it to be a fact, as have many of the engineers with whom I have worked. It is a sound rule to prepare for trouble when the pressure exceeds 20 pounds.

Many other factors come into play, such as the use of oxy-acetylene or other metal-cutting plant in confined spaces, but these have to be considered individually.

Symptoms.—The symptoms are dramatic in onset and in kind. Usually in about thirty to sixty minutes after the man has left the air-lock he is suddenly taken ill with violent pain. This pain is very often about the flexures of the knees or elbows, but of course may occur at any other site, most commonly in the chest. The pain is really of great severity, and the patient will writhe and twist in a truly alarming fashion shouting loudly for help. If the pain is in the chest, spitting of blood usually occurs. Fortunately the cerebral blood-vessels are not very often affected, and, in a group of about a hundred cases, I have only once seen a case of cerebral embolism. In this case, fortunately, the medical air-lock was quickly available and the condition cleared up after recompression and very slow decompression without leaving any apparent permanent damage.

The length of the time between the workmen leaving the air-lock and the onset of symptoms is unfortunate as it will be evident that the man will usually be some distance from his work before he is affected. It was therefore our custom to furnish all workers with a letter of identification requesting that he should be returned to us immediately for treatment. This prevented the patient from being detained by the Police or being removed to some hospital where the proper treatment could not be carried out.

Treatment.—This may be summed up into the one word recompression, and the more quickly this is carried out the more satisfactory the result will be.

The Recompression Chamber or Medical Air-lock is usually situated at ground level and near the shaft exit. It is fashioned much the same as an ordinary air-lock but, of course, only requires one door opening inwards, and in the door there is a small window in order that one may see how the patient is progressing. This chamber should contain couches, should be well heated, and hot tea or coffee in flasks should be always available.

The patient is placed in the chamber and the pressure gradually raised until it is 2 or 3 pounds higher than the pressure at which he had been working previously. There are also arrangements for the admission of fresh air into the lock. The beneficial effects of the treatment are very soon evident for, by the time the pressure has reached the desired level or shortly afterwards, the patient passes from his state of acute distress into one of painless comfort and will very often lie down on the couch and fall asleep.

This optimum pressure is maintained for a short time and then the slow process of decompression is commenced and will usually take a period of from two to three hours to complete, varying naturally with the severity of the symptoms. Quite often the pain will return at varying periods from a few minutes to a few hours and in these cases the patient must again be compressed and decompressed, taking even longer time over the decompression.

I have found that if a patient has been in the medical air-lock for periods amounting in all to about five hours, further recompression is not desirable. At our "workings" we had accommodation for bedding the patients who had not reacted well to treatment in the medical air-lock and further treatment consisted of laying them up in with plenty of hot water bottles and liberal injections of morphia repeated as often as necessary. This line of treatment never failed to be effective.

In very severe cases where apart from the "bends" the patient looked badly shocked, one had to enter the lock along with the patient and administer oxygen, which seemed to help a great deal.

In event, as sometimes happens, of the lock not being available through another patient occupying it, the administration of oxygen is helpful and should be carried on with until the morphia has acted or the lock has become available. I was always in the habit of giving the patient two ½ gr. morphia suppositories to take home with him after being in the medical air-lock, a precaution which probably saved me many night calls.

In a series of about a hundred cases of varying severity we had no casualties which proved fatal and no cases of permanent incapacity. Some men certainly refused to work in the compressed air again, but that was simply a matter of taste—" once bitten twice shy."

I hope that this memo, sketchy as it may be, will prove of interest to some. If anyone would like fuller details on any points, I would be only too pleased to correspond, as, being interested in the condition, I would like to hear of the experiences of others. An exchange of views is, in my opinion, always helpful.

BRIDGING BY RUSSIAN ENGINEERS AND SAPPERS.

The story was told to-day how Russian engineers and sappers secretly built a bridge within 150 yards of German sentries to enable tanks to cross the river on the central front and to open the offensive where the enemy least expected it. The problem facing the engineers was to build the bridge beneath the surface of the river the existence of which the enemy from his vantage points on the higher right bank would not suspect until zero hour. For two days sappers worked in the forest, shaping piles and planks for the bridge and bringing them down a small valley, out of sight of the Germans, to the water's edge. A replica of the bridge was built behind the Russian lines, and it was found that stout pillars packed with stones would support tanks without the necessity of building a top to the bridge. A method was also evolved by which enemy tanks would not be able to use it in the opposite direction. Moreover, its construction had to be such that it could be put together in darkness and without the use of hammers. Each plank was fitted with bolts and marked with cuts which the builders could recognize by touch.

Thin ice was forming on the river when, one night, all was ready for the sappers to start work. They worked up to their chests in freezing water, and were obliged to take every precaution to avoid splashing as they pushed the timbers before them and carried stones in baskets along the shore. They finished two sections of the bridge on the first night, but so bitter was the cold that it was impossible to work for more than short spells. The next morning the Germans saw nothing unusual in the river, for everything lay two feet below the surface. On the second night the sappers had to work under rifle fire, and some were killed or wounded ; but on the third morning several sections of the bridge were complete.

Then the river froze hard, and for many days the bridge lay invisible under the ice. There were anxieties that the level might fall, revealing the pillars, but the secret was kept. At last the time came for the offensive to begin. The ice was now strong enough to bear infantry. At zero hour they surged over to the German bank, and the tanks, guided by the chief engineer, also crashed across. The ice was splintered and shattered as the heavy machines left the river's edge, but seven pillars held, and the astonished enemy saw a barrier, which he had believed to be impassable, broken. The Russians soon had a foothold, and drove the Germans far back from the river.

(*The Times* 3.12.42).

MAJOR-GENERAL J. C. RIMINGTON, C.B., C.S.I.

MAJOR-GENERAL JOSEPH CAMERON RIMINGTON, C.B., C.S.I., who died suddenly on the 30th April, 1942, was born on the 20th September, 1864, and commissioned Lieutenant, Royal Engineers, from the Royal Military Academy on the 15th February, 1884. On leaving the S.M.E. he was fortunate in proceeding at once on active service in Burma for which he received the medal and two clasps. After this he joined the M.W.D. and served in many stations, including, in 1895-97, the Special Defences Division in Bombay, and, in 1901, the Samana District; in 1902 he became Assistant D.G.M.W. at Simla. In 1910 he was again at Simla as D.D.G.M.W. and on the outbreak of the European War he was a Colonel and C.R.E., 4th Division, at Quetta. From 1915 to 1919 he was Engineer-in-Chief in Mesopotamia and was seven times Mentioned in Despatches and received the C.B. in 1916 and the C.S.I. in 1918. After the war he became Director General, Military Works, at Army Headquarters, and held the post until his retirement with an Indian pension in July, 1921. General Rimington was twice married. His first wife, Amy Gordon, daughter of Major-General H. G. Waterfield, Indian Army, died in 1923. They had two sons and two daughters. He married secondly in 1932, Mrs. Lœtitia Scott. She died in 1933.

Brigadier Sir Edward Tandy writes:

General Rimington has been a valued friend since I first served under him in 1893-94, when he was garrison engineer at Agra. This was soon after his marriage, and he and his charming wife were at various stations with me in Northern India later on, at intervals of a few years. But as I was not serving in the Military Works Department I have no first-hand knowledge of the long and valuable services which brought him to the head of it at the end of his career.

I was again under his orders in Mesopotamia and acted for a few months as his Brigade Major at A.H.Q. Baghdad. It was in 1916 that R.E. work in Mesopotamia was most difficult, owing to the climate, sickness, and the dearth of skilled labour and materials and of decent food. Like Wordsworth's "Happy Warrior," Rimington was an ideal chief when things were at their worst, as his magnificent health of mind and body kept him equable and cheery in conditions which broke up too many good men.

During his four years as Engineer-in-Chief, Mesopotamia, he held us together as a band of brothers, tackling his own job without fuss and counting on others to do the same. He never paraded his successes or allowed failures to damp the cheerful ardour with which he faced whatever might come next. Few of us could have guessed at that time how much he was feeling the loss of his elder son, who was killed in France in 1916, as a subaltern of the Cheshire Regiment. His sincere faith and his constant thought for others enabled him to face events with a robust simplicity which was an example to us all.

He also never mentioned in those trying days that if his advice had been taken the disaster of Kut-el-Amarah and some of our worst troubles in Mesopotamia might have been avoided. According to the story, which I heard many years later, after our defeat at Ctesiphon he was ordered to examine Kut-el-Amarah and report on its suitability as a defensive position for the retreating army. After inspection he wired that it was most unsuitable. Unfortunately his advice was not taken.

I understand he got his rugger colours at "the Shop," and I knew him as a strong useful player at most games. He would have made a great admiral, with his passionate love for the sea and the boyish spirit of adventure which was with him to the last. Thus when over seventy he went off alone for a winter voyage in a German tramp steamer round the Black Sea and Eastern Mediterranean, in

Maj Gen Joseph C Rimington CB CSI

bitter cold weather, with a few German officers as his sole companions—though quite ignorant of the German language!

As near neighbours in London we often met between 1932-40, when I learnt of his schooldays at Westward-Ho with Rudyard Kipling and "Stalky & Co." He had known Kipling again in his early days in India and occasionally later, and was a keen supporter of the Kipling Society, as well as of the Royal Empire Society and the Royal Society of St. George. He himself wrote and published a life of Alfred the Great, who was his favourite hero.

During these last years he did constant personal work in aid of poor patients, as an active member of the Cancer Relief Society, who have expressed their deep sense of loss at his sudden death. He was actively helping them to the last, and he wrote to me shortly before his death saying what a heavy time he had had receiving a very large number of donations sent to the Society in response to a broadcast appeal.

On the outbreak of war he took up active work with the A.R.P. and L.D.V. and was locally very helpful in the initial stages; though he had to give them up later as too strenuous for a man of nearly 76. He enormously appreciated the last public event of his life, which was to attend at Buckingham Palace to see his second son, Commdr. M. G. Rimington, receive the D.S.O. and bar for his exploits in the Mediterranean, as commander of H.M. Submarine *Parthian*.

He was chairman of "The Somerset Folk Society" and enjoyed organizing their annual gatherings in London, being himself an excellent example of the words of the old song:

"Somerset men are courteous,
Somerset men are wise.
You can always know a Somerset man
By the kindness in his eyes."

BRIGADIER-GENERAL W. F. H. STAFFORD, C.B.

To one who at the S.M.E. in the middle eighties studied Survey under Stafford memory recalls an outstanding period of Corps Cricket and Football, and Stafford as an outstanding member of both teams. He was in those days captain of the Soccer and his character in *The History of R.E. Cricket* describes him as a painstaking and useful bat, a good field, and an asset to most Corps sides, even in the days of Renny-Tailyour, Fellowes, Friend and Dumbleton. It adds that he had the knack of always rising to the occasion and his best performances were against the strongest teams.

William Francis Howard Stafford was born on 19th December, 1854, in India, where his father, Colonel, afterwards Major-General, W. J. F. Stafford, C.B., was commanding an Indian regiment. During the Mutiny his mother had to flee with him to safety. He was educated at Wellington and the R.M.A. and received his commission as Lieutenant, Royal Engineers, on 29th April, 1873. On leaving the S.M.E. he went to India and was posted to the Bengal Sappers and Miners at Roorkee, and with them saw service in the Afghan War of 1878-80. Definite sanction for a military telegraph organization was only given on the eve of hostilities and two companies of the Sappers were hurriedly equipped as telegraph units. The 6th Company, under Lieutenant Stafford, was attached to the

Peshawar Field Force and laid a line as the Force moved forward. He brought the line into Gundamuk with the advanced guard, being at one time actually ahead of it, and this performance proved a revelation to the Superintendent of Civil Telegraphs who followed in rear. Stafford was present at the Lughman and Hissarak Valley operations and was mentioned in Despatches. In 1881 he served in the Mahsud-Waziri Expedition and gained another Mention. In the following year he returned to Chatham and in March, 1883, was appointed Assistant Instructor in Survey at the S.M.E., a post which he held for five years. In February, 1884, he married Edith M. C. Carr, daughter of Mr. F. C. Carr-Gomm, of the Madras Civil Service. He was promoted Captain in January, 1885. After some service at Norwich, in 1890 he went to Cairo to command the 24th Company and remained there until 1895, obtaining his Majority in November, 1892. He moved with the 24th Company to Malta before returning home. At home he took over the command of the 7th Field Company at Chatham, and went with it to the Curragh where he remained until the outbreak of the South African war. He went out to South Africa in command of the 26th Company, which in November, 1899, formed part of Methuen's force and was with the 7th Division when it entered Bloemfontein, and it participated in the actions of Poplar Grove and Karee Siding in the Orange Free State. He became Lieut.-Colonel in April, 1900, and C.R.E., 3rd Infantry Division, and remained in the Transvaal until 1902. For his services in the war he was mentioned in Despatches and received the C.B., two medals and five clasps.

In 1902 he was appointed C.R.E., Cork District, and in the following year was moved to the North-West District, Chester. He became Colonel by brevet on 10th February, 1904, and in 1906 was appointed Chief Engineer, Southern Command, at Salisbury, with the rank of Brigadier-General, and held that post until his retirement in August, 1910.

During the European War he commanded the South Irish Coast Defences for about a year from June, 1915, and in 1917 he went to France as an Area Commandant on the Somme and remained there until the enemy offensive in March, 1918.

A few more words about his prowess at sports and games. At Wellington he won all the sprint races; in 1874 he played Rugby for the English Twenty against Scotland and for North against South, at the Oval; he was a member of the R.E. Soccer team when they won the Cup in the season 1874-5; he played cricket for the Corps both when student and Instructor at the S.M.E.; and when Chief Engineer at Salisbury he played regularly for the South Wilts Cricket Club. After his retirement he went to live at Crowthorne and there he took an active interest in the games of his old school. His figure on the touchline of Bigside is probably well remembered by many of the younger generation now serving in the Corps. It is an interesting fact that at the time of his retirement, he, his two brothers, and his son, now Brigadier J. H. Stafford, O.B.E., M.C., were all serving on the active list of the Corps.

He died at Crowthorne on the 8th August, 1942. It has been written of him: "He was a favourite always and never made an enemy."

F.E.G.S.

Brig Gen William F H Stafford CB

BRIGADIER-GENERAL C. H. FOOTT, C.B., C.M.G.

INFORMATION has recently reached England that Brigadier-General C. H. Foott, C.B., C.M.G., died in Australia on the 27th June, 1942. He was an Honorary Member of the Institution of Royal Engineers and for some years before 1926 our Corresponding Member in Australia.

Cecil Henry Foott, son of Mr. T. Wade Foott, of Springfield, Co. Cork, and of Dunoon Station, Queensland, was born at Burke, Darling River, N.S.W., on the 16th January, 1876, and educated as a Mechanical Engineer. In 1896 he received a Commission in the Queensland Permanent Artillery, and five years later transferred to the Royal Australian Engineers. He was Director of Engineers, Australia, from 1909 to 1911. In 1912-13 he did the Staff College course at Camberley and qualified *p.s.c.*; in 1914 he studied at the Royal Naval College, Portsmouth, and for a few months in the latter year was D.A.Q.M.G., 2nd London Division (T.F.).

During the European War of 1914-18, he served with the A.I.F. in Egypt, Gallipoli and France, and was Brigadier-General and Chief Engineer to the Australians in France when they won their final brilliant successes. He was seven times Mentioned in Despatches and received the brevets of Lieut.-Colonel and Colonel in addition to the C.B. and C.M.G.

He commanded a Brigade in Australia from 1923 to 1929 and was District Commandant, Victoria, from 1929 to 1931. From 1921 to 1934 he was A.D.C. to the Lieutenant-Governor and from 1927 to 1931, A.D.C. to H.M. the King.

Our sympathies go out to our brother Officers of the Royal Australian Engineers on the death of this distinguished Military Engineer.

F.E.G.S.

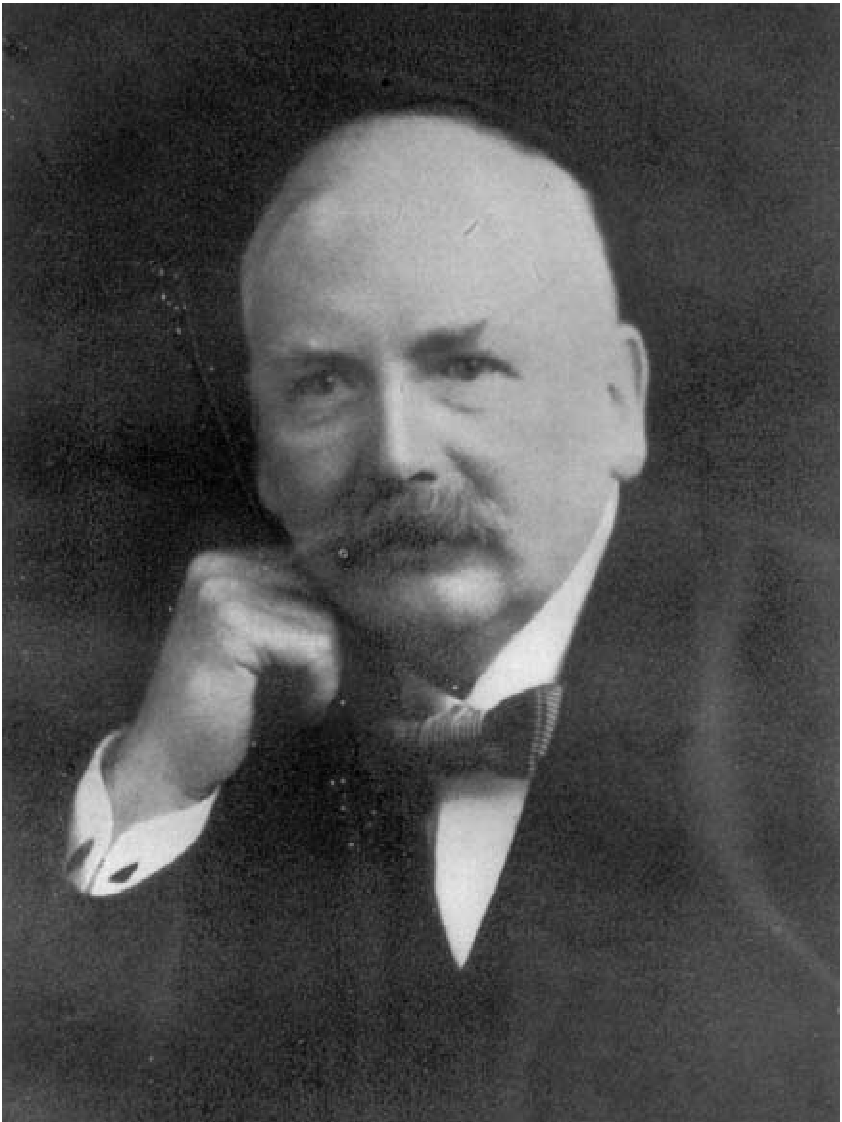
CAPTAIN G. T. McCAW, C.M.G., O.B.E., M.A.

ALL R.E. Officers concerned with survey will have heard with regret of the death of Captain George Tyrrell McCaw, C.M.G., O.B.E., M.A., Honorary Member of the Institution of Royal Engineers, who died on 17th October, 1942. Dear old "Macca"—as he was known to many—was the elder son of the late Mr. Robert McCaw, of Lurgan, County Armagh, Northern Ireland, and was born in 1870. After graduating with distinction at Trinity College, Dublin in 1893, he joined the Irish Land Valuation Department, with which he remained for ten years. The work, however, did not greatly appeal to him, nor give much scope to his mathematical and scientific turn of mind. In 1903 an opportunity for more congenial work presented itself when he heard that an appointment was being offered for work on the geodetic survey of South Africa. Thereupon he resigned his appointment and commenced his survey career.

As the origin of this appointment has considerable interest to the Corps, it may be worth saying a little about it here. The appointment had been engineered by Sir David Gill, then H.M. Astronomer at the Cape. Soon after Sir David's arrival in South Africa in 1879 ("Darkest Africa" as it then was), he became interested in the survey of the sub-continent, and to that end prepared a scheme for a geodetic triangulation covering the four constituent states, Cape Colony, Natal, the Orange Free State, and the Transvaal. His idea was to cover the country with a gridiron of geodetic triangulation modelled on the great trigonometrical survey of India, and eventually he succeeded in persuading the Cape Colony and Natal Governments to make a start. The work was entrusted to an

R.E. party under Captain (later Colonel Sir William) Morris, R.E., which started operations in 1883 and carried on for nine years, the results being published in 1896.

In preparing his scheme Gill had, from the outset, envisaged the extension of the triangulation over the whole continent. On the 26th September, 1879, soon after his arrival in Africa, he wrote to the High Commissioner, Sir Bartle Frere, proposing the measurement of the Arc of the 30th Meridian "as the first step in a chain of triangles which ultimately will connect Natal with the Mediterranean and Alexandria." He continued later in his letter: "I have no doubt that the work will ultimately be done. Perhaps the present generation will not live to see its completion, but it is a great work that, I believe, will yet be performed." The "great work" has, perhaps, taken longer than Sir David expected, but nearly half of it is now finished and a substantial fraction of it has been done by officers and men of the Corps. Sir David continued to interest himself in the extension of the triangulation, and in August, 1897, the triangulation of Southern Rhodesia was officially placed under his direction by Earl Grey, who was then Administrator, the intention being to observe an east and west chain through Bulawayo, and a north and south chain which would form part of the 30th Meridian Arc. By this time Sir David had managed to interest Cecil Rhodes in the enterprise, and the latter insisted that before the Rhodesian chain was carried southwards, it should be carried northwards as far as Lake Tanganyika. He undertook to find the funds for the northward extension if the Transvaal could be induced to arrange for the extension from the Orange Free State up to the Limpopo. In 1901, Gill was in correspondence with Lord Milner and the Intelligence Division of the War Office on the question of the geodetic survey of the Transvaal and the Orange River Colony, and eventually, in 1902, it was decided to go ahead with the work, which was placed in charge of Morris and completed in 1905. Meanwhile arrangements were proceeding for the observation of the Rhodesian Section, and a party under a Swedish geodesist, Dr. S. T. S. Rubin, was formed to observe the north and south chain through Rhodesia. McCaw's appointment was to this party as Rubin's assistant. Work started in 1903 and continued for three years. Then a financial blizzard struck South Africa and funds ran short, Cecil Rhodes died, and the Chartered Company could not undertake to continue its support, though further efforts by Gill, assisted by Sir George Darwin, succeeded in raising £1,600 in order to effect the junction on the Limpopo, between the Rhodesian work and the survey of the Transvaal, and thereby fulfil the pledge to Rhodes. This work was executed by another R.E. Officer, Captain H. W. Gordon. This was the last spasm before the "great work" came to a halt. The idea, however, was not dead, and after an interval of two years, McCaw came back to survey work and the 30th Meridian Arc when he joined a party under another R.E. Officer, Major (afterwards Brigadier) E. M. Jack, R.E., which had been left behind by the Uganda-Congo Boundary Commission to observe the section of the arc lying between 1°11′ north and 1°11′ south. This part of the arc followed approximately the line of the recently demarcated boundary, and the opportunity of the presence of the boundary surveyors was seized to observe a further section. After a short spell of leave in 1909, McCaw was then selected by the Colonial Office to replace Captain C. H. Ley, R.E., the Officer in charge of the Trigonometrical Survey of Fiji, who had had to relinquish his post on account of ill-health. McCaw stayed in Fiji until 1915 (except for another spell of leave in 1912, during which he spent most of his time completing the computations of the Uganda work and helping to prepare the report for publication) by which time the field work was finished. Much office work still remained, as McCaw had made use—for the first time—of the stereoscopic methods of photographic surveying devised by Major F. Vivian Thompson, R.E., and the computation and plotting of his observations, and the preparation of his report (which was published by Messrs. Stanford in 1917)



Captain G T McCaw CMG OBE MA

took another full year. On completion of his report on Fiji, McCaw volunteered for military service and was commissioned in the Royal Engineers. He went out to "Maps G.H.Q." in France as a Captain on the staff of the Depot Field Survey Battalion. Here his main job was to knit together the networks of triangulation observed by the various armies, and to co-ordinate this with the native trigonometrical material. He also had to study many new and important map projectional problems arising out of the application of rectangular grid systems to cartography. His services proved so valuable that when peace was restored a special post was created for him in the Geographical Section of the General Staff at the War Office. Here his official duties were to study the triangulation systems of the countries in which the British Army might have to operate, and to maintain suitable records of these for Army use; but with his strong mathematical bent and qualifications it was not long before he became interested in the geometric and projectional problems of air photography, and in 1921, when the Air Survey Committee came into existence, he became its first secretary, retaining this post, in addition to his other duties, until his retirement from the service in 1936. He received the Civil O.B.E. in June, 1924. During his service in the G.S.G.S. he was also Joint Secretary of the Colonial Survey Committee, in which capacity he took a prominent part in the organization and running of the periodical conferences of Empire Survey Officers. There is no doubt that his genial personality and numerous friends among Colonial Surveyors contributed not a little to the success of these gatherings. It was at one of these, in 1928, that the idea of a technical journal, in which reports of new methods of surveying, instruments, etc., could be published, was propounded by Brigadier Winterbotham. The idea was warmly welcomed and the support of the Colonial Office having been secured, the *Empire Survey Review* came into existence; McCaw, whose qualifications were outstanding, being selected as the first editor, a post which he held until his death. McCaw retired from the service in 1936 when his services to Empire surveying were recognized by the award of a C.M.G.

It will be seen from the above that McCaw's association with the Corps has been close and long. He was appropriately made an Honorary Member of the Institution of R.E. in 1925. After his appointment to the G.S.G.S. he became a sort of professional guide, philosopher, and friend to many an R.E. Officer called upon to wrestle with abstruse problems of geodesy or map projections. And when, after a long interval, work on the 30th Meridian Arc was resumed in 1931—by yet another R.E. party, this time under Major M. Hotine, R.E.—McCaw's experience and advice were of the greatest assistance.

McCaw became, in fact, the geodetic adviser to the G.S.G.S. and to the Corps, building up for himself a reputation as a geodesist which had become international before he retired. His death is a sad blow to many friends in the Corps, and a great loss to Empire Surveying.

M.N.M.

CABLEWAY BRIDGES.

345. Army tries out cableway bridges: Anon. *Engng News-Rec.*, 1941, 127 (15), 491-2.

Cableway bridges are now being used experimentally by the U.S. Army to replace pontoon bridges. The equipment, consisting of two welded tubular steel towers, a $1\frac{5}{8}$ in. steel cable and carriage, an anchorage system, a lifting winch, and a hauling winch, can be carried on two lorries, and erection can be completed in three hours. The cableway can be used for spans up to 1,000 ft., and can transport fifteen 13-ton vehicles per hour over a 400 ft. span; 27-ton tanks can be carried if two parallel cableways are used. The rate of transmission may be as great as 15 m.p.h. once the load is in position. This type of bridge eliminates the difficulties of finding suitable bridge sites and approaches, and permits flooded areas or dry ravines to be easily bridged. The cableway is not readily seen from the air and is easily camouflaged. Erection and haulage are described.

All Reviews of Books on military subjects are included in the provisions of K.R. 547(c) *1940*.

BOOKS.

(Most of the books reviewed may be seen in the R.E. Corps Library at Brompton Barracks, Chatham.)

WHAT THE CITIZEN SHOULD KNOW ABOUT THE ARMY ENGINEERS.

By Lieut.-Colonel Paul W. Thompson, Corps of Engineers, U.S. Army.
(Published by W. W. Norton & Co. New York) 204 pp. with diagrams and illustrations. Price $*

* Price not shown.

Colonel Thompson modifies the title of his book by dedicating it only to " all those citizens who *wish to know* . . . something about the Army Engineers," and he is right to do so for, although written in popular language and full of bright passages, it is essentially an army primer. It essays to tell how the Corps of Engineers " stands ready to blaze the way to victory " for the army of the U.S.A. in the present war.

As an introduction to the pages dealing with the Corps in modern combat, it begins with some description of the origin and development of that Corps ; and here readers of *The R.E. Journal* will find much to interest them in comparing the early histories of the American Army Engineers and our own. The first appearance of Engineer Units in the American Army was in 1775 ; but all such units were mustered out " lock, stock and barrel " in 1783. The true birthday of the Corps was March 16th, 1802, when Congress passed an Act providing for a thorough reorganization of the whole army and for the setting up of a Corps of Engineers, a small corps but a separate one. It was stationed at West Point and one of its functions was to organize and operate a military academy which served the entire army but was specially an agency of the Corps. As in the case of our own Royal Engineers, the establishment consisted of officers only at the beginning ; but the Mexican War of 1846 gave occasion for the inclusion in it of " other ranks," and the year 1861 saw the establishment of a battalion of Engineer troops. By 1916, this battalion had risen in two long strides to a strength of three regiments (nine battalions). The immense expansion of the Corps in the last Great War and again in 1942, is given in some detail ; but need not be quoted here.

Engineer Institutions came into being *pari passu* with the development of the personnel establishments. In 1869 an " Engineer School of Application " was opened, and from it has grown the present " Engineer School " at Fort Belvoir, Virginia, described as " the heart and soul of the Corps." There is also located at Fort Belvoir the " Engineer Board " whose duty it is to ensure the suitability of every item of Engineer field equipment.

In one essential particular the American Corps differs from ours. It is responsible in peace for " improvements to rivers and harbours," a great national responsibility, and Colonel Thompson points proudly to such achievements as the control of floods in the Mississippi valley and the construction of the Panama Canal. These and their like are purely civilian works and a perpetual responsibility. The organization to meet this responsibility comprises eleven engineer " divisions," each sub-divided into several " districts," each controlled by a Lieut.-Colonel with four or five officers to assist him. District officers serve normally for only two to four years ; but continuity of policy is ensured by a permanent establishment of civil service employees. Some idea of the scale of this organization is given by the fact that on 1st January, 1942, the number of civilian employees engaged on the construction and maintenance work of the Corps exceeded 600,000 !

Another responsibility thrown upon the American Army Engineers, but not on ours, is due to their Aviation Service being a part of the army and not a separate and independent Force. This necessitates specialized Engineer Units for building, maintaining and defending air-fields. The " Aviation Regiment " in peace consists of a headquarters and three battalions, with an establishment of 66 officers and 2,200 enlisted men.

In the American Army the selection and training of Engineer officers differ widely from our methods. All army cadets receive the same training at West Point. At the conclusion of their course, the graduates required for the Engineer Corps are found by examination, tempered by selection ; and in practice this system has had the effect of posting to the Engineers those who graduate at the top of their class. After receiving his commission as Second-Lieutenant, the young Engineer officer normally spends "two years on duty with troops; two years on duty with 'Rivers and Harbours' in an Engineer District; one year as graduate student at a leading engineering college; and one year as a student at the Engineer School, Fort Belvoir." Thus, in his first six years of service he will have become "both a finished Engineer officer and a graduate Civil Engineer." Space does not permit of further quotation, but the pages devoted to the training of Engineer N.C.Os. and men are equally interesting.

The mission of the modern Corps of Engineers is defined as two-edged, involving both constructive and destructive operations to facilitate the movement of our own troops and to impede the movement of the enemy. The functions arising therefrom are enumerated and the organization of units to carry out those functions is described in some detail. The author divides all Engineer Units into two classes, *viz. general* units ("Jacks of all trades") and *special* units prepared to accomplish certain tasks requiring special technical skill and equipment. Among the latter will be found Camouflage, Ponton (*sic*), Mapping, Railway and Supply Units, most of which operate behind the Front. No mention, however, is made of the routine-employment of either officers or other ranks in peace-time; nor is there any indication of an establishment of officers exceeding the number required for what we call "troops and companies."

In the typical field-army, the *general* units will comprise perhaps 75 % of the total Engineer strength. The very wide variety of their tasks is emphasized, including as they do "throwing a foot-bridge or ponton (*sic*) bridge, demolishing a structure, laying a mine-field, erecting an anti-tank obstacle or establishing a water-point." With these functions in mind and insisting upon the fact that the Corps of Engineers is traditionally a *Combatant* Army, Colonel Thompson proceeds to explain the organization of all Engineer Units and to consider their suitability for modern war. This constitutes what may be considered the kernel of his book, all that has been written above being as it were, the shell of the nut.

He begins with a short essay on the nature of modern war and finds that the introduction of "the gasolene engine" has re-established the art of maneuver (*sic*) and has again placed in the hands of the commanders the possibility of battles of annihilation. The essential military characteristic of the "gasolene-powered instrument" is, in his opinion, its ability to *move* and to carry fire-power fast and far. This ability, however, depends not only on the engine, but also on the routes available; and that is where the engineer enters the picture. The organization of all Engineer Units in the field-army is given in detail; but, before proceeding to demonstrate how they are prepared to fulfil the high role which war will thrust upon them, a chapter is devoted to seeing how engineers have actually stood the test of *blitzkrieg* in the present war. This review, however, does not go much beyond the German campaign of 1940 in the Low Countries and Northern France. Its value will be better assessed when the lessons of Libyan deserts and Russian steppes have also been considered.

Chapter VI "*How the Army Engineers will Function in Battle*" is, undoubtedly, the most interesting in the book and will give readers much food for thought and discussion; but it would be unfair to quote from it unless there were space for full-length quotation, and space is not available. Some idea of its range, however, may be gleaned from the titles of its sub-divisions, e.g., Engineer Reconnaissance; Assault Operations; The Forcing of River-lines; Barrier Operations; Demolitions; the Tactics of T.N.T.; Organization of the Ground. The next chapter deals with Engineer functions behind the Front to which reference has been made already. These two chapters fill 75 pages, i.e., more than one-third of the whole, and will well repay study from end to end.

The book concludes with a brief summary followed by a glance at the future. This notice of it may conclude with the pious hope that some British author will arise to expound equally well all that should be known by our military-minded civilians and some others, about the Royal Engineers, not forgetting India's Sappers and Miners and the Works services. Such a book would, also, come as a much-wanted text-book for the instruction of our Y.Os. of all Arms.

T.F.

A CURIOUS DEFINITION.

Bastion.—In fortifications, a bastion is a kind of tower placed in an important position, especially at a projecting angle from which it is possible advantageously to fire upon an enemy. Architecturally, it is a fortification in the strengthening sense only, but it can be entered just as though it were used for military purposes. Bastions are generally fitted with staircases.

(*Sir Christopher Wren: His Life and Times* (p. 144). By C. Whitaker-Wilson, 1932).

PARATROOPS.

By Captain F. O. MIKSCHE.

(Faber & Faber. Price 10s. 6d.)

This is, in every sense of the word, a remarkable book. It is " deserving of notice " because it is the first attempt which has been made in this country to formulate a reasoned and comprehensive doctrine for the employment of Airborne Forces: it " excites admiration " for its logic, its wealth of historical and factual detail, and its breadth of vision: it is " extraordinary " because, unlike the majority of similar publications in the Press, it faces up to the problems of detail—the minutiæ—on which so many grandiose, but impracticable, conceptions are doomed to founder.

After a brief survey of the conception and development of the idea of Airborne Forces, the author summarizes the history of their use in battle—in Norway, the Low Countries, the Balkans, Crete—with detailed analyses of outstanding operations such as the capture of Fort Eben Emael and the Isthmus of Corinth, and the invasion of Crete. He goes on to formulate a tactical doctrine, his object being not " to lay down hard and fast rules " for the employment of Airborne Troops, but to enumerate " the guiding principles which should form the basis for their tactical handling. " This he does, in relation to offence, counter-attack, mobile defence, invasion, pursuit, and *coups-de-main*, his conclusions being argued convincingly and with due regard to the fundamental principles of war.

There follow three masterly chapters dealing with the technical problems involved in the landing of a large force by parachute and glider; supply and maintenance; organization of the move; and intercommunication. Two further chapters on the tactical handling of the Landing Head, and the use of the Air Arm in support, precede what is by no means the least remarkable section of the book, that devoted to defence against this form of attack. In these final chapters every aspect of defence is considered, and sound practical solutions offered to the problems involved. Having drawn his own conclusions, the author adds this significant passage: " In England the question has been approached differently. The several branches of the Military and Civil Organizations co-operating in the Defence of Britain enjoy an apparently large measure of autonomy, and they stand in reciprocal relations which are better expressed by ' association ' than by ' subordination.' Our continental logic fights shy of any such solution; for as we see it, such forms of organization make it very difficult to demarcate clearly powers and responsibilities. This may lead to unsound compromises between the different branches of the defence organization which in an emergency will have unfavourable repercussions . . . . Hence the necessity of a unified command which at the crucial moment will have at its disposal all branches of the defence organization and handle them as the situation demands. True co-ordination is conditional upon a unified control—which implies subordination. But a book published in England would hardly be complete unless it took account of the point of view for which that country stands. . . . ", which the author does by allowing " his friend Mr. C. R. Fay " to state the case as an Englishman in academic life sees it. Whether the succeeding apologia for the democratic viewpoint justifies itself must be left to the reader's judgment.

This review would not be complete without one final quotation from the text. " The world of military science stands, at the moment, at a great doctrinal crossroads. No wonder that under the present circumstances diverging fingers point to one or other extreme. Some promise victory by air power; others by tanks. The underrating of an air arm is a dangerous thing: the overrating of it no less so. No arm by itself is fully decisive. It forms only one more or less important cog in the complicated machinery of modern warfare." The secret of success lies in the purposeful combination of all the cogs, in the common march of the assembled war machine to victory.

A.C.S.

THE CASE OF DR. BRUENING.

By BERNHARD MENNE.

(Hutchinson & Co., Ltd. Price 1s.)

In this pamphlet the author traces the tortuous plottings in Germany after the last war which in 1930 brought Dr. Bruening, of the Catholic or Central Party, to the Chancellor's chair, a position which he held for about two years, and in that time helped to complete the end of popular government in Germany. He is now an exile in America and is said to be a lecturer under the name of Brown at Harvard University. Perhaps Dr. Bruening may come forward after this war as a candidate for the office of Saviour of the Reich, and in view of this this little book, written by one who hardly poses as a friend of the Doctor, will be welcome as throwing some light on his character and methods.

F.E.G.S.

MALAYAN POSTSCRIPT.

By Ian Morrison.

(Faber & Faber Ltd. Price 8s. 6d.)

Few descriptions by eyewitnesses of the swift and tragic Malayan episode are available, and this account is the more vivid, since it was written by the author in the heat of his disgust at the outcome and within three months of his escape from Singapore. No attempt is made to give a history of the ten weeks' campaign. It is merely a day to day record of the startling events as they occurred, the reactions of the populace and the grim endurance and heroism of the troops. Owing to the somewhat optimistic official statements, this retreat was so unexpected by the public that it upset their self-assurance, and as usual the commander was the obvious scapegoat. The author however does not consider General Percival to blame, though he admits that the G.O.C's personality was not inspiring. Lack of troops, lack of aeroplanes, lack of a good defence line, etc., all combined to render Singapore untenable and no leadership could have made prolonged resistance possible. Ian Morrison has given a very lucid account of what he saw and heard during his ten weeks with the troops in Malaya. He is well acquainted with the Far East, as the son of "Chinese" Morrison of the "Times" should be, and this book contains not only details of the fighting, but also an interesting description of the country, people and form of government. Of the Fifth Column there was little evidence, and the Malays are acquitted of active hostility, though they were undoubtedly apathetic.

But with a population composed of more than seven nationalities, and with no common loyalty to weld them together, it is not surprising that they did not rush to arms, especially as no arms were available. The author blames the authorities for lack of preparation, especially after the occupation of Indo-China, but our forces at that time were inadequate for our world-wide commitments, and we had to guard the vital places.

More serious is the charge that the British inhabitants knew little about the Malays and other nationalities, and did not attempt to understand them. The author considers that "the arrival of white women in the tropics has had an adverse effect upon the men. In the old days both officials and planters had their native mistresses—they were closer to the people of the country." This point of view was held by several distinguished Indian civilians at the end of the last century, and probably lack of knowledge of the natives is one of the many causes leading to Indian unrest.

The public will be less ready in future to allow themselves to go soft and to disarm, if they take to heart the lessons so well described in this short story of the biggest British disaster of the present war.

C.G.F.

SEA-FLYERS.

By C. G. Grey.

(Published by Faber & Faber, Ltd., November, 1942. 256 pp. Price 7s. 6d.)

The purpose of this little book is "to tell people what they ought to know" about flying over the sea. In it the term "Sea-Flyers" embraces both the men and their machines. People who have no expert knowledge of aeroplane-construction will find Part I "*As it was in the beginning,*" more interesting than the later chapters which deal with the development of sea-flying machines between the two Great Wars, development both in the U.S.A. and at home. The creation of the R.N. Air-Service and the personal references to the pioneers of sea-flying before 1914, make a very attractive story. The author's suggestion of an alternative to the convoy system for sea-borne transport and his ideas as to there being still a future for Air-Ships will give every reader some food for thought. His recital of the specifications of sea-flying machines produced between 1918 and 1939 is, however, in too great detail for ordinary people to appreciate. It deals with machines for all sea-flying purposes, not with war-machines only; and in the case of war-machines there is hardly any mention of armament. The reason for the omissions is fairly obvious; but they detract from the interest of the subject. We may assume that it is for a similar reason that there is little reference to the achievements of sea-flyers (both men and machines) in the present war.

This would be a pleasanter book to read if the author had omitted his jibes at "senior admirals" and at the responsible authorities whom he dubs "bureaucrats." "Perhaps its chief appeal lies in the fact that it provides, in some sort, an introduction to the Air Ministry's recent publication, *Coastal Command*.

T.F.

COASTAL COMMAND.

Issued by the Air Ministry.
(Published from H.M.'s Stationery Office; 143 pages in paper cover; numerous illustrations. Price 2s. od.)

Coastal Command worthily completes a trilogy of which the two preceding numbers are *Battle of Britain* and *Bomber Command*, all three being compiled by Mr. H. St. G. Saunders, Asst. Librarian of the House of Commons, and sponsored by the Air Ministry.

Mr. Saunders has written supremely well this official account of the part played by Coastal Command in the battle of the seas from 1939 to 1942. It tells a great story, and is written with admirable restraint. It contains no heroics or hysterics, no personalities, no "journalese"; but it is crammed with the material for superlatives.

"The battle by air and sea is relentless and there is no pause. In the air the brunt is being borne by Coastal Command," whose triple task in co-operation with the Royal Navy is to "find the enemy; strike the enemy; protect our ships." How comprehensive is that task will be realized as never before by the average reader of this book. Nor is it only a record of achievement in action. It also describes briefly but with admirable lucidity the organization which makes such achievement possible. The part played by the W.A.A.F. is not forgotten.

A large number of photographic illustrations add to the attractiveness of this publication. Among many which are marvels of clarity, "The picture that sank a battleship" (the *Bismarck*) is outstanding.

T.F.

TRANSPORTATION AND TOTAL WAR.

By P. C. YOUNG.

(Published by Faber & Faber, Ltd., November, 1942. 144 pp. Price 6s.)

This is a highly technical and conscientiously argued *brochure*, and the author is very much in earnest. Holding that the demand for inland transport to-day outruns the possibilities of supply, he puts forward a scheme for reorganizing the transportation under war conditions of passengers, goods and minerals between points in Great Britain. The period for the continuation of war conditions is estimated at five years; but, as most of the changes recommended appear as desirable in total peace as in total war, this estimate need not be queried. The non-expert will find some of Mr. Young's chapters pretty stiff reading, especially those dealing with prices and costs; but every traveller and every consignor of goods or parcels will find points of interest in the section headed "Operation." There is, however, no word of comfort for the ordinary passenger who is tired of man-handling his own suitcase! The author foresees considerable criticism of his scheme. Moreover, its adoption to-day would appear to be perilously like swapping horses in midstream. It is perhaps some such foreboding which leads to the suggestion that these new methods should first be experimental within an area outside Great Britain; *e.g.* the six counties of Northern Ireland, "Try it on the dog," in fact!

T.F.

"KAMPFE DER PIONIERE"

(German Engineers in Battle),
By COLONEL DR. ROSSMANN.
(Berlin, Franz Eher, 2.85 RM.)
(Translated from the *Militär Wochenblatt.*)

The object of the book, to which the Inspector-General of Engineers and Fortresses, General Jakob, contributes a foreword is, in the first instance, to give the Homeland some idea of the activities in war of the engineer arm. In the historical survey of the origin and development of the arm it is worthy of remark that in the creation of the present German Army, by wise provision, the establishments of the engineer battalions received by comparison with the other arms a considerably greater increase. This measure has fully justified itself. In the second chapter the various tasks of the engineers in war are simply explained without technicalities. Speed was the hall-mark of the campaigns of 1939 to 1942, in which the engines of the aircraft competed with the engines of the armoured vehicles. Three kinds of obstacles, however, offered opposition and still offer opposition to the rapid advance of armoured troops and the motor-borne troops operating with them. These are first, natural obstacles, especially rivers, the passages and bridges of which have been destroyed by the enemy. Secondly, artificial obstacles of all kinds, such as the blocking or cratering of roads and the setting of land mines. Thirdly, permanent fortifications in the form of pill-boxes (*Bunker*). Sometimes two, even all three of these obstacles were found in combination. In every case cries for the expert, the engineer, were raised. This does not mean that the other arms stood still and left the work to the engineers: they also gave a hand in all. The engineers, however, took charge because they had been trained for the purpose and had special knowledge.

The other numerous engineer duties are only lightly touched on. Such as the lay-out of fortifications, blocks and minefields; the construction and repair of roads; also the cratering and destruction of roads and railways, etc.

The Fortress and Railway Engineers, and the Armoured and Mountain Engineers are briefly mentioned. In the third part of the book the actual operations of the engineers in all the theatres of war are described. In chronological order we accompany the engineers from the creation of the West Wall through the years 1939 and 1940 to the campaign against Bolshevism on the 22nd June, 1942. The last part contains a great number of excellent photographs of the work and fighting of the engineers.

J.E.E.

THE FIRST BATTLE OF THE TANKS.

By J. H. Everest.

(Arthur H. Stockwell, Ltd., Ilfracombe. Price 3s. net.)

In view of the public interest taken in tank warfare during the present conflict, this interesting account, written by a soldier who served throughout the 1914-1918 war in the ranks of "Kitchener's Army," gives a vivid impression of the difficulties experienced in the pioneer stages of tank development and the resulting improvements in design and organization, in connection with which the names of Generals Sir Hugh Elles and Sir Ernest Swinton are especially mentioned. The author makes no claim to present anything like a historical record of events nor does he advance any theories; his book deals mainly with the Cambrai battle of November, 1917, and the subsequent heavy counter-attack made by the Germans at the end of that month. The concluding chapter reviews the findings of the Court of Enquiry afterwards held to investigate the causes of the losses thereby sustained. Illustrations of early types of tanks are given, with a sketch map of the Arras and Cambrai battle area.

J.H.

AN INTRODUCTION TO THE STUDY OF MAP PROJECTION.

By James Mainwaring.

(Macmillan & Co., London. Pp. viii + 114. With diagrams 6 in. × 9 in. Price 5/-.)

In the foreword it is stated that the book is written especially for candidates taking the Higher School Certificate and for first year University students. But most budding geographers will find the book a clear and useful introduction to a subject of some interest to them. The treatment is rightly elementary and is largely, though not entirely, geometrical. The whole work is written on the assumption that the earth is a sphere. It is provided with a wealth of explanatory diagrams and figures, an admirable feature.

Here are a few notes which may be found useful when a new edition is called for. The last sentence on page 19 might give the wrong impression that all orthomorphic projections distort shapes as much as Mercator's. The sentence on page 35 that "in general they (the errorless parallels) are a sixth of the total range of latitudes" should be corrected to read "an approximate rule for the selection of the errorless parallels, so as to give a minimum of scale error, is to place them at one-sixth of the total range from the uniting parallels; thus for a total range from 30° to 60° N. the errorless parallels may be taken at 35° and 55°N." On page 55, and elsewhere, there is a description of a "Normal Zenithal Projection, when the plane is tangent to the sphere at a point on the Equator." In "Germain," which is usually followed, the word "Meridional" is used instead of "normal," which might be misunderstood.

Perhaps too much importance is given to Gall's Projection, which has very few merits. The old *Plate Carrée*, or better still, the Simple Rectangular, can be relied upon to give better "pictorial" results.

But it would be a mistake to end upon a note of criticism. The book is admirably produced and should be genuinely helpful to beginners, to whom it may be confidently recommended.

C.F.A-C.

MAGAZINES.

INFANTRY JOURNAL.

(*November*, 1942.)—*Maps, Strategy and World Politics.* By R. E. Harrison and R. Strausz-Hupé.

The writers describe the different methods by which cartographers attempt to show the round surface of the earth on a flat and rectangular piece of paper. Such devices are known as projections. Map-making has limited itself to controlling distortion, so that one of the four properties—distance, direction, shape, or area—is shown correctly at the expense of the others, or else to achieve the best compromise among them.

For navigation purposes—where the true compass direction between points is required—we must use Mercator's projection. For studying great circles we must use the gnomonic projection. Both methods have many disadvantages. Mercator's projection is true at the equator only; the regions adjacent to the poles cannot be shown at all, as they fade into infinity.

The best form of map for the study of world strategy—on a single map—is probably the North Polar Azimuthal Equidistant projection, in which the North Pole is the centre, and linear scale is made true along radii from the pole along the meridians. The map might extend from the North Pole to the 30th parallel south of the equator. From the Pole within twenty degrees of the equator there is remarkably little distortion, and the area includes all the major world powers and all the major fighting fronts except the south-west Pacific Islands.

All maps that cover a large area are necessarily misleading, and it is inadvisable to make constant use of the same map in a fixed position. Nor is it necessary that all maps should have the north at the top of the paper. The globe has no top. It is useful to turn maps upside down, or to point them in a direction which might represent the point of view of an individual or a nation, as, for example, a Briton's view of the Continent, or Hitler's view of the Middle East.

Machine Warfare. Part Three.

Major-General J. F. C. Fuller contributes his final article on *Machine Warfare.* In this instalment he deals with "The Machine Defence" and "The Problem of Invasion."

It is laid down that the General Plan of Defence should, in every situation, include a system of anti-tank works and a mobile counter-attacking force, generally kept well in rear and towards the more exposed flank, so that any attempt to turn the works may be attacked in the flank or rear.

General Fuller's views on invasion are of particular interest at this time. Even in past centuries conditions have very seldom favoured an overseas invasion of a country in which a would-be invader has no previous footing. Turning to modern times, the whole picture becomes vastly complex. Not only has surprise been restricted by the impossibility of hiding the assembly of a large invading army, but the complexity of that force itself has limited the landing places to well-equipped ports. If opposition is to be expected, landing on an open beach is no longer a practical operation until landing stages, wharfs, quays, etc., are built.

A reference is made to the landing at Suvla Bay in August, 1915, which illustrated the extreme difficulty of landing even in the face of weak opposition, but the case is not a good one, as the mistakes made are unlikely to be repeated.

When opposition is likely to be met, night is the only practical period during which a surprise landing can take place. Reconnaissances of a defended beach or port are impossible except by air; consequently the invader is doubly blind. If, however, landing places should not be occupied by the enemy, as in the first landing of the Japanese in Korea in 1904, then time—and not the bullet and shell—is the deciding factor.

This introduces the velocity machines—the aeroplane, the tank, and the motor vehicles—all three of which have drastically modified the problem of invasion, to the disadvantage of the invader.

First, it is obvious that in all major wars an invading army must be motorized. This complicates the problem of transportation by the number of war machines and vehicles that will have to be shipped, and the disembarkation difficulties will be enormously multiplied. Hence the landing of heavy guns, tanks, vehicles and engineer stores on an open beach is no longer a practical operation of war. Ports, and well-equipped ones at that, must first be seized, and their seizure will occupy time.

Secondly, it is equally obvious that it is not necessary for the defender to split up his motorized forces into as many groups as there are possible landing ports. If the British were to invade France, and if the enemy's mechanized and motorized forces were concentrated, say, at Bourges, they could reach most of the practicable landing ports within 72 hours.

The transport of an invading army 500,000 strong would require at least twenty convoys of twenty ships each. This would mean a constant stream of ships moving backwards and forwards, for weeks on end. Each convoy would have to be strongly escorted.

At the points of disembarkation strong opposition, both by air and land, must be expected. These points must be fully equipped, and they must be located within range of the invader's land-based fighter planes; hence they will be few in number, and the enemy will probably have anticipated the points of attack.

In order to mitigate the resistance offered, it will be necessary to clear the ground by a series of preliminary invasions, with the object of seizing and holding well-equipped ports and suitable airfields in their vicinity. This must be done in a very brief space of time—72 hours at most in the above case of France.

The next proceeding is debouching from the bridge-heads established. This is one of the most difficult operations of war, unless the would-be invader can base his forces on the country of an ally or on a locality so far distant from his enemy that he cannot be interfered with for weeks and even months on end.

General Fuller concludes his article with a plea for the amphibian tank, of which he has been a strong advocate since the last world war. It is a matter for regret that experimental work in this direction was dropped, on grounds of economy, soon after it had been started.

(*December*, 1942.)—*Mines by the Millions.* By Lieut.-Col. P. W. Thompson.

The anti-tank land mine is the only man-made obstacle so far devised that can stop a tank and is, at the same time, light, portable, and easy to instal. A tank charging into a mine-field has far less chance of coming out alive than an infantry-man advancing recklessly against machine-guns and barbed wire.

Tanks, however, do not charge recklessly through mine-fields, but along lanes from which the deadly explosives have been cleared away. This work of removing the mines is a grim and specialized operation entrusted to the Engineers.

The modern anti-tank mine is usually a steel-shelled cylindrically shaped little package about 16 inches in diameter, 4 inches in thickness, and containing some 10 lbs. of T.N.T. Exploding under a tank, it will shatter the track, and may breach the tank's belly and maim the crew. The individual portion of T.N.T. is, however, small, and, by itself, can control very little area. It is, therefore, thickly sown in mine-fields consisting of row upon row of hundreds or thousands of individual mines.

The Engineers, to whom the task of clearing a mine-field is assigned, have a choice of two methods: one is to remove the mines individually; the other is to contrive to make them explode harmlessly.

In the removal method, the first step is to find each individual mine in the lane to be cleared. The probability is that the enemy has buried and carefully camouflaged each one. The oldest method of finding a mine is still the surest, and consists of poking and prodding the ground with a sharp-pointed instrument such as a bayonet. The engineer soldier pokes and prods his way along, searching every square foot of ground, and is careful to prod before he treads. He has to bear in mind that the mine has a hard shell (usually of steel), that it is buried only a fraction of an inch deep, and that his mission—and his life—depend upon his unceasing care.

When the prod encounters anything hard, the engineer scrapes away the earth covering, examines the detonator carefully, and decides how to disarm it. He does not know whether he has succeeded until he lifts the mine and hands it to a comrade to carry back to the dump.

Even an old hand at mine removal can never take a single thing for granted. A favourite trick of the Germans is to lay two mines together, one exactly on top of the other. The bottom mine is equipped with a special detonator which is set off by a pull instead of by pressure. The trigger of the pull-detonator is attached by means of a thin wire to the base of the top mine. The idea is that the engineer, having disarmed the top mine, will proceed to lift it, and so detonate the bottom one. The trap is avoided by passing a knife blade under the base of the mine before lifting it.

Mine removal presents the greatest difficulty when it has to be carried out by night or under fire.

To simplify the location of mines, a device known as a mine detector has been invented and is in use in most armies. But the engineer soldier does not like the idea of being burdened with it when under fire. In that case, the old reliable poke-and-prod method is still the favourite. The mine detector, triumph of physics though it is, has its chief use in clearing mine-fields which have been captured intact.

The second system of mine removal, that of sympathetic detonation, works on the principle of the Bangalore torpedo. The latter, in its usual form, is a 20-foot length of ordinary cast-iron pipe filled with T.N.T., and fitted with a detonator. If such a torpedo is pushed across a mine-field and detonated, all near mines on either side detonate in sympathy. The result is a mine-free path, several feet long, through the mine-field. Obviously the path can be widened or lengthened by using additional torpedoes.

There is one catch, however; the near-by mines sometimes fail to explode, and engineers working towards an enemy mine-field would do well to bring along prodding rods as an extra precaution.

A new sympathetic-detonation method was used by Marshal Rommel when he took Tobruk. He could not afford to waste the time that a Bangalore torpedo attack would occupy. His method consisted in employing waves of dive-bombers, who swept in from the west just as the vanguards of the Panzer divisions reached the mine-fields at the perimeter of the forts surrounding Tobruk. The dive-bombers' targets were the mine-fields themselves. There was method in their bombing : they dropped their eggs so as to form lanes of craters straight through the fields, from the outer to the inner sides. Through these lanes the Axis tanks swarmed, accompanied and followed by Axis infantry. This was the beginning of the end for Tobruk.

But the ease and speed with which the Stukas handled the situation at Tobruk should not lead to a false impression. Normally, dive-bombers will not be available in sufficient numbers, nor, if available, are they likely to be allowed to operate with impunity. The clearing of mines will continue to be a job for engineer soldiers on the ground.

The mission of the latter will always be made hazardous by enemy counter-methods. Chief among these will remain the *anti-personnel* mine, a lethal device introduced by the Germans in the autumn of 1939. It had an arrangement whereby the mine, on being tripped, was boosted a few feet out of the ground before exploding. This was an interesting feature, since the effect of a bomb detonating a few feet above the ground is much greater than that of one detonating on or under the surface. The mine was really a shrapnel bomb which, on detonation, covered a wide area with deadly steel pellets. It was tripped by the slightest tug of any of numerous wires which were stretched along the surface of the ground, hidden by grass and leaves.

One method of dealing with this class of mine—employed by the French—was to drive animals over a suspected mine-field.

It is a common practice to intersperse anti-personnel explosives amongst anti-tank mines, a possibility against which the clearing engineer must always be on his guard. Not only is this true of the mine-fields themselves, but in any territory reoccupied from the enemy he must be on the watch for " booby traps." This hidden weapon consists of a small charge of T.N.T. and a detonating fuze which is set off by any minor movement, such as a slight tug on a fine wire.

In a sense, the booby trap is to the soldier what the anti-tank mine is to the tank. In the first case, as in the second, the solution to the problem is—engineers. It is up to the engineers to enter the suspect areas, to delve around with knife blades and prodding irons, to ferret out the fine wires, and, with velvety touch and iron nerves, to follow them up to the trap itself and render it harmless. It is a business in which the motto reads : " Your first mistake is your last."

Among the major worries of the mine-clearing engineer are mines that do not explode, *i.e.* dummies. A dummy mine may be a block of wood, shaped like the real thing. Buried and camouflaged, such a fake can cause a lot of trouble. Only after he has found and unearthed the dummy, examined it and made sure that it is not attached to an underlying live trap or mine, can the mine-clearer relax. Even then, he cannot know whether the next mine will not be the real thing with all the fancy booby trap attachments.

A.S.H.

REVUE MILITAIRE SUISSE.

(*July*, 1942.)—*Idées de manœuvre du haut Commandement Français* (1939-1940). By Capt. E. Bauer. An analysis of the French plans of operations on the Western front in 1940. It is too soon, of course, to write the history of the disastrous campaign of France, but Captain Bauer has given a concise analysis of the French plans, so far as available information permits.

During the operations in Poland, the Germans left only a comparatively small force of 20 to 25 divisions to watch the French on the Western front. How well informed they must have been as to the state of unpreparedness of both British and French ! Yet both Britain and France had joined in the war to help Poland.

General Gamelin had only 31 regular divisions, two light motorized divisions and only one armoured division. How could there possibly have been any invasion of Germany to relieve Poland ?

As soon as Poland had been disposed of, von Brauschitch began transferring divisions to the West, and preparing for his next stroke. There was no immediate attack on France. Indeed, all through the winter of 1939-40, the French were nibbling at the German advanced positions. No great losses were incurred in this process ; the author gives the French figures of casualties from September, 1939 to May, 1940 as 2,609 killed, 6,700 wounded and 2,871 missing or prisoners.

What were the Germans likely to do ? Clearly, they would not make a frontal attack against the Maginot Line. They would, in all probability, turn the French line of fortifications in the north by a wide sweep through the neutral countries. A movement through Switzerland, especially after the conclusion of the Italo-German alliance, was not improbable, but General Gamelin considered it more likely that the main thrust would come in the north.

Before the collapse of Poland, the French High Command made dispositions for covering the northern line. The 1st Group of Armies (General Georges) took over the line from Rochonvillers (north of Metz) to the North Sea. Included in this Group were the Second Army (General Huntziger), the Army of the Ardennes (General Corap), the First Army (General Blanchard), the B.E.F. (General Gort), and the Seventh Army (General Giraud).

The situation was complicated by the obstinate neutrality of Belgium. Would the Belgians ask for help in time?

While Italy remained neutral, a considerable part of the Army of the Alps was withdrawn to strengthen the line further north; 6 divisions were taken away. If Belgium called for assistance, the First Army might have time to establish itself along the Scheldt, where, with the Belgian Army of 16 divisions, an Allied Left Wing might get on the flank of a German thrust through Flanders.

Meanwhile, the German concentrations were increasing towards the north. A great mass of 57 divisions was assembling between the Moselle and Maestricht, and from 20 to 22 divisions along the Dutch frontier. During November, the Belgian Army was increased to 18 divisions—about three times the size of King Albert's Army of 1914—and Gamelin had hopes of being able to get as far as the Dyle, and possibly join hands with the Dutch. An attenuated "Maginot Line" was begun by the Belgians to duplicate the Dyle. Preparations were made for moving the French Ninth and First Armies rapidly to the German-Belgian frontier between Sedan and Namur. The B.E.F. was to hold the line of the Dyle and effect a junction with the Belgian Army. The Seventh Army was to be held in reserve on the extreme left. (*To be continued.*)

Commentaires sur la guerre actuelle. At the time of writing, the great German offensive on the Eastern front had started. This year, the objective was the Ukraine for its wheat and the Caucasus for the oil. The initial successes of the Germans had carried them to Voronesh and the Don. The cutting of the Moscow-Rostov line had deprived the Russians of the power of manœuvring their reserves; and there was a grave risk of the separation of Marshal Timoschenko's armies from those of General Schukov. If the Germans could reach the Volga, the great line of supply from Persia and Irak through the port of Astrakhan would be lost to the Russians. This situation, if it did not entirely cripple the Russian armies in the south, would be a deadly blow to them.

The commentator notices a change in German tactics. The breaking of the front to admit a spear-head which would penetrate deeply into the defence had been carried through to the point of staleness. The Russians as often as not had counter-attacked these isolated "spears" and cut them off. Now, the spearheads were replaced by armoured units in squares, which carried their own artillery preparation, motorized infantry, and anti-aircraft defence; even their own workshops. Such a formation automatically protected its flanks and rear. The Germans claim that this formation allows action not only in front, but in all directions, according to the tactical situation.

Meanwhile, the fortress of Sebastopol still held out. Furious assaults on it were being made by the Germans to remove the threat to their right flank as they advanced to the Don.

(*August*, 1942.)—*Idées de manœuvre du haut Commandement Français.* By Capt. E. Bauer.

The confusion of ideas which existed in the French High Command was not diminished by the virtual establishment of two General Headquarters, those of General Gamelin at Vincennes, and those of General Georges at La Ferté-sous-Jouarre. Comings and goings multiplied.

Early in 1940, the German strength on the frontiers of Holland and Belgium steadily increased. In December, 1939, it was estimated that 68 German infantry divisions were grouped in that direction. In January, 1940, the number had increased to 80. Alarms for the second time recalled Dutchmen and Belgians from leave; but still their two Governments hesitated. In the face of the great avalanche that fell upon them in May the doubts and hesitations of the victims seem tragic and criminal.

This growing menace to the Low Countries could only be met by a swing forward of the Group of French Armies under General Georges, and the French staff worked hard at perfecting the details of the bound forward to the line of the Dyle. Until the Belgian Government, however, made up its mind to resist and call in the Allies, nothing more than preparations could be carried out.

It was clear that the rush forward to link up with the Belgian and Dutch forces would lead to gaps unless time allowed for the move to be completed. General Georges' original plan was to use Giraud's Seventh Army as a reserve to the Northern Group of Armies and then to move it up to occupy the Scheldt region below Antwerp and on the left of King Leopold. But in March, Gamelin proposed that the Seventh Army should go further and take up a position about Breda, to link the Belgian and Dutch Armies. The whole Allied line would thus become patchy.

This change did not commend itself to Giraud. It involved a march of 230 kilometres, while the Germans had only 110 kilometres to go to intercept him.

The manœuvre of the Dyle put into operation by Gamelin on May 10th, 1940, involved the movement of a "mass of manœuvre" leaving its prepared positions, not to take the chances of a great encounter battle, as Joffre wanted to do in August, 1914, on the Sambre and in the Ardennes, but simply in order to occupy a better defensive line.

In the sequel, General Billettes' Army Group was surprised in the act of movement.

The French disaster had its roots in divided strategic counsels as well as in political disunity.

L'homme et la machine dans la guerre moderne. By Maurice Bagnes. An appropriate article which calls attention to the dangers of too much entanglement with mass mechanization. So long as all goes in accordance with the plan, elaborated to the extent that the Germans can go, the power of the machine over the man can be guided. But what if events do not develop in accordance with the scheme?

The author, writing in August, 1942, touches upon a very pertinent theme.

Commentaires sur la guerre actuelle. The German drive towards the Caucasus was in full swing. By the middle of August the Germans had almost reached the furthermost limits of their advance, but they had not yet reached Stalingrad. They had achieved no decisive result. Von Bock was attempting to drive an attack on Stalingrad from the south, pushing northwards from Elista. The Russians were losing heavily in the Don Valley, but at Voronesch they were holding firm—and how much they have benefited now by their stand there!

Reference is made to the threat to Russia by the presence in Manchuria of a Japanese army reputed to be half a million strong.

In the Middle East, the British had been driven back into Egypt, and the commentator remarks on the superior anti-tank weapons of the Germans. He also refers to the better co-operation between Rommel's air forces and his ground troops. The situation appeared to be all in favour of the Germans.

(*Sept.* 1942.)—*Commentaires sur la guerre actuelle.* All attention was being centred on Stalingrad. The Russian counter-attacks to disengage Leningrad, the diversion around Rjeff and the German progress towards the Caucasus were all eclipsed by the battle for Stalingrad. Already Hitler was hurling his best troops against the city, which seemed likely to become the final objective of the summer campaign of 1942.

The Battle of Voronesch in July was the prelude to the battle of Stalingrad. It was fought to secure Von Bock's left flank while he crossed the Don and moved south towards the Caucasus. Then Krasnodar and Maikop fell, Novorossisk and Mozdok. The oilfields of Grozny were endangered. There the pressure on the Caucasus was eased, and Von Bock turned his attention on Stalingrad. The terrific and extravagant onslaughts on the city succeeded one another with incredible ferocity. Trench warfare and house to house fighting took the place of the *blitzkrieg* methods of the open warfare. The Russians hung on to the city to save their hold on the Volga and to gain time for the rebuilding of their Armies.

A remarkable feature of the campaign is the refusal of the Russian Black Sea fleet to be beaten, in spite of the loss of Odessa, Sevastopol, Kertsch, Rostov and Novorossisk.

(*to be continued.*) W.H.K.

ARMY EDUCATION.

(*September,* 1942.)—In his article *Educational Training and Education* Brigadier C. G. Maude, D.S.O., O.B.E., M.C., draws attention to the difference between the pre-war and present-day ideas of "Education in the Army," in the former case it was called Educational Training.

Though, in the main, the basic idea was the same in pre-war days as it is to-day, owing to that perennial weed, financial pressure, which demanded concrete evidence of value for money expended, the Educational Training developed into a form of "pot hunting"; the training of the mind tended to be subordinated to the passing of examinations for the trophies (Certificates of Education), which were displayed as the tangible evidence demanded.

Brigadier Maude points out that, in addition to this, the tradition of instruction in the Army was inevitably an authoritative one and so Educational Training tended to become an extension of child education and the principles of adult education receded into the background. When in 1940 it was decided to initiate "Education in the War-time Army" it was at once clear that methods which, up to a point, satisfied the conditions of a small professional army in peace were not applicable to a citizen army at war; in addition this Education was intended to have a wider scope, its object being not only to make a man a better soldier but also a better citizen and a better individual.

The writer points out that one subject, Current Affairs, under the A.B.C.A. scheme, has proved the value of the discussion method of instruction and draws attention to the advantages of this method for many other subjects in adult education (which in a democracy is training in citizenship).

Another article dealing with adult education—*Education in an Army awaiting Demobilisation* by Lieut.-Colonel G. P. Chapman, O.B.E., M.C.—draws particular attention to the special problems to be dealt with in the period following the cessation of hostilities.

The writer's main object is to stimulate thought now, so that a considered plan, instead of *ad hoc* improvisation, may be ready when the time comes.

No attempt is made to lay down the details of such a plan, but one line of approach is suggested. This is to combine the training or re-training of the man in the calling, manual or clerical, which will occupy his working hours when he returns to civil life with that in other directions which are needed for him to be a useful citizen out of working hours as well.

Lieut.-Colonel Chapman's broad idea that, as George Bourn's wheelwrights were once masters of their craft and part of the culture and society of Farnham, so each craftsman, through his trade, could be brought to be a living part of the community and not an insentient cog, should be an incentive to many to work out for themselves just how it can be realized.

Of the articles dealing with the practical details of Army Education *Filming Education* by Serjeant Instructor D. B. deB. Nicol, M.A., A.E.C. is yet another example of what can be achieved by keenness and initiative.

The writer tells the story of the making of a film, with the happily chosen title of New Horizons, of the educational activities of a Signal-training Regiment.

Apart from being an entertaining story, the article proves, if proof were necessary, that sound methods will produce "active participation in educational activities."

Human Interest in Army Education by Bdr. Maurice Pearlman, tells how the special circumstances of Army life have been used to help towards education by means of "the sure ingredient" for success employed by Newspaper Editors, viz.: Human interest.

The article gives, in some detail, the methods adopted and records the increase in attendance and interest displayed in Education since this new method was adopted.

One point, if not the main one, is that the change was brought about by a few heroes who decided that what had hitherto been wrong was not the men's lack of interest in Education but their own "method of presenting our Educational functions."

The Last Days in Burma by Major S. H. Lowes, A.E.C., is a most interesting account of his experiences in his fortunate and exciting escape out of Burma.

Experiments in Teaching Illiterates by Mrs. Blanche Suckling, is a technical article which should be of considerable value to any faced with the problem of teaching men whose knowledge of written English is so poor as to be useless for all practical purposesn

A.R.A.I.

THE INDIAN FORESTER.

(*September*, 1942.)—The August number of the Journal has not yet reached this country; this is unfortunate, as the September number includes the second part of an article which contains a reference to Lieut.-Colonel Bailey, the only R.E. member of the Indian Forest Service, who, after his active service was Lecturer in Forestry at Edinburgh University. He is reported to have said, presumably some time in the nineties, "We urgently require two or three model forests of limited area, to be owned and managed by the State." The author of the article, in parenthesis, says, "We have not yet got them."

Mr. V. D. Limaye records an interesting experiment on two wooden trusses of 40 feet span. One was made of the M.E.S. type with steel gussets and strap joints, the other with solid wooden disc dowels, incidentally costing only half of the former. In a test consisting of applying increasing loads to the panel points, the M.E.S. pattern failed at 3½ tons total load, while the other stood up to 7 tons. The experiment was watched by the C.R.E., Meerut District, so presumably engineers in India know of the results. There is an excellent photo, but diagrams of the joints would have been more useful still.

(*October*, 1942)—Wood waste, shavings and sawdust, are now being used to make a very high class of paper, leaving the rest of the log for other purposes.

An extract from another paper tells of the dangerous habits of the swordfish. One has been known to penetrate the copper sheathing of a wooden ship, an inch of under-sheathing and three inches of hard wood; presumably it had mistaken the vessel for a whale, which it is known to attack, as many swords are sometimes found in those animals' hides.

A tree planting machine, an American invention, is described. It will plant up to 8,000 trees or shrubs in a day, with as good results as if the trees were hand-planted.

F.C.M.

CORRESPONDENCE.

AN IMPROVISED BRIDGE.

To the Editor, *The Royal Engineers Journal*.

SIR,

The December, 1942, number contains a very interesting description of an improvised bridge by Major Cockerton. It does not appear that the bridge was ever tested to its designed load. In my opinion this should always be done, whether the bridge is built for training or for actual use. A test is particularly important in the case of a complicated bridge involving much calculation. In this case certain assumptions were made which may not have been justified.

When I commanded a Field Company I made a point of putting every bridge built by the Company to the severest test to which it would ever be likely to be subjected in the load class for which the bridge was designed. Such a test not only satisfies everyone that a good job has been done but it also brings out any weaknesses there may be. These should be rectified and a fresh test done.

There is no need to take any risk with one's G.1098, because the test can start well below the designed loading and work up. For example a bridge designed for Class 5 can be tested with a 15-cwt. truck empty and driven slowly, finally loaded with men and driven fast. Then a 30-cwt. lorry empty and slow and finally loaded with a D.W. load to 5.5 tons as given in the Load Classification Table and driven fast with loose bits of scantling on the deck to add to the impact. If a weakness occurs at any stage it must be rectified before carrying on with the test. This looks as if it would take a long time but, if the bridge is safe for the designed load, there will be no hitch and the whole test should not take more than an hour or so. If weaknesses occur which have to be rectified, then the bridge as it stands is a snare and a delusion.

All this does not apply to straightforward spans with piers and steel or timber joists whose strength can be calculated with certainty but I think Major Cockerton will agree that a bridge of the kind described, although excellent in every way, is not subject to precise calculation and should not therefore be considered safe for the designed load until tested.

I should be grateful if you would publish this letter.

Yours faithfully,

T. W. R. HAYCRAFT, *Brigadier*.

SAPPERS AND ENGINEERS.

To the Editor, *The Royal Engineers Journal*.

SIR,

The *Daily Mail* of Tuesday, February 9th, contains the following passage. Speaking of the work done by the Technical services of the 8th Army it says :—

" *Sappers and engineers* more than anyone made the Army's advance possible."

Is this quite unimportant, or does it exemplify a growing tendency in common parlance to reserve the term " engineer " for the man who makes or repairs an " engine," in the sense of a prime mover ?

Any such tendency would have, of course, important repercussions for our Corps, which are so obvious that I need not enlarge upon them.

I am, Sir,

W. A. F. KERRICH, *Colonel*.