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MILITARY ENGINEERING.

PART IIIB.

MILITARY BRIDGING.—BRIDGES.

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MILITARY ENGINEERING.

PART IIIB.

MILITARY BRIDGING—BRIDGES.

SECTION VII.—FLOATING BRIDGES.

Boats and rowing drill.

1. The following are the common technical terms used in connection with boats and their equipment, viz. :— Description boats, &c.

(*a*) OF A BOAT (Pl. I., Fig. 5).—The *bow* or *stem* CF, the *stern* EH, the *quarter* the portion of each side between E and M, the *keel* HF, the *ribs* to which the planking is fastened (inside the boat not shown in the plate), the *bottom boards* laid on the ribs at the bottom of the boat to prevent the ribs and planking being injured, the *thwarts*, I, K, L, &c., or seats for the rowers, the *row-locks*, N, M, D, &c. (in some boats *thole pins*, in others *crutches* are used); when not in use, the rowlocks are closed by pieces of wood called *poppets*; the *gunwale* CDE, or upper plank of the boat's side; *painter* or rope fastened to a ring in the bow by which the boat is made fast to a mooring, &c. (in large boats painters used at each stern quarter are called *sternfasts*); the *rudder* EHZ, and *tiller* (not shown) by which the rudder is moved. In light boats a *yoke* and *yoke lines* are substituted for the tiller. *Double-banked* boats are those, such as cutters and pinnaces, in which two rowers sit on each thwart; *single-banked*, such as gigs, whale-boats, and dinghies, have one rower on each thwart. The *starboard* side is that on the right hand of the coxswain as he faces the bow, the *port* side that on his left.

(*b*) OF THE OARS.—The *blade* is the flat part at the end, and the *loom* the part between the blade and the *handle*. Oars are said to be *shipped* or *unshipped* as they are placed in the rowlocks or laid in the boat, when their blades should be towards the bow. *Sculls* are short oars, used in pairs, one in each hand.

(c) Of an anchor.—The *flukes* G and O (Pl. II., Fig. 4) are those parts that hold the ground; the *crown* P, the part midway between the flukes; the *shank* PQ, the *stock* RS, the *washer* and *key* for keying the stock to the shank, and the *ring* T. To *cast* an anchor is to heave it overboard, while to *weigh* it is to raise it from the bottom.

A boat may be *ahead*, *astern*, or *abreast* of another, or *abeam* when to one side, or on its *quarter* when astern to one side, or on its *bow* when ahead to one side. The rising tide is called the *flood*, and the falling tide the *ebb*. A vessel is said to be *moored* when it is made fast to a floating object secured by two or more anchorages.

Equipment of boats.

2. The following is the proper equipment of boats:—

Equipment for ordinary ferry work.

Cutters—

One oar for each rowlock, including bow oars.
One boathook for each side of the bows, laid in hook forward.
One short boatbook for the stern, laid in hook aft.
One fender for each rowlock.
One gangboard.
One rudder.
One tiller.
One painter.

Wherries and other small boats—

One oar for each crutch.
One boathook in bow.
One fender for each rowlock.
One rudder.
One yoke, and yoke lines.

Additional equipment for long journeys or rowing drill.

Cutters—

One spare oar for each side.
One bailer.
One lifebuoy, with breastline attached.
One anchor, cable, buoy, and buoy-line.
One keg of water.

Wherries and other small boats—

One spare oar.
One short boathook, in stern.
One bailer.
One lifebuoy, with breast-line attached.
One anchor, cable, buoy, and buoy-line.
One keg of water.
One gangboard.

Rowing drill.

3. With crews under instruction the instructor (coxswain) will fall in the crew in two ranks for double-banked boats, in one rank for single-banked, and number them. Nos. 1 are *bowmen* and the highest numbers are *strokes.* For double-banked boats the front rank will be *port oars* and the rear rank will be *starboard oars.* For single-banked boats the odd numbers will be starboard oars, the even numbers port oars. **Manning a boat.**

The crew, while under instruction, will not be told off permanently to the places in the boat, but will each perform the work of bow oar and stroke oar in turn; the non-commissioned officer in charge will keep a roster for the purpose—the stroke oars on one day becoming bow oars on the next day, and the stroke oars being taken by the men on the aftermost thwart but one.

MAN 1ST (*or* 2ND) GIG *or* CUTTER. The boat-keepers drop the boat alongside, ship the rudder, and place the gangboard when necessary; then the crew file into their places in the boat, and sit square on their thwarts, with their knees together, and their feet against the *stretchers* or *footboards*, which should be adjusted to keep the knees well bent. The bowmen stand up, holding on by their boathooks. The others unship poppets, if necessary, and toss oars, taking care that the edge of blades are in the direction of the wind. The crew are then *proved*, if under instruction.

The usual way of *proving* (or ensuring that each man knows his number) is to call out the man's number, on which he should raise his left arm to the full extent above his head, and keep it there until the next number is called. The last man to be proved drops his arm on the word "DOWN." **Proving numbers.**

4. When ready to start the coxswain gives the words—

SHOVE OFF FORWARD. The bowmen shove off with their boathooks, and all hands get in their fenders.

DOWN OARS. On the command "DOWN OARS," which will not be given until the boat is clear, the men lift the oars till the handles are clear of their knees, allowing the blades to incline outwards and fall flat on the water together, taking care that the blades strike the water before the looms touch the gunnels; they then lay hold of the handles with both hands, backs up, thumbs round the handle, and place the oars in the rowlocks.

STAND BY TO GIVE WAY. The men get ready to row, leaning forward, and extending their arms.

GIVE WAY ALL (*or* PORT, *or* STARBOARD). The crew, or those named, give way together. The bowmen lay in their boathooks, sit down, and give way in time with the rest, taking care that they toss their oars and let them fall into the water together. The time of each stroke is taken from the port stroke oar. The oars should be dipped so as just to cover the blades, and in the return stroke they should be feathered by dropping the wrists and bringing the elbows close to the sides. The crew should not look at their oars except in rough water.

HOLD WATER ALL (*or* PORT, *or* STARBOARD). The crew, or those named, hold the water, wrists slightly dropped, without allowing their oars to move either backwards or forwards.

BACK WATER ALL (*or* PORT, *or* STARBOARD). The crew, or those named, back water together; this word should not be given without previously checking the boat's way.

STAND BY TO LAY ON YOUR OARS —OARS. This caution is given when it is necessary to stop rowing without laying in oars.

At the word "OARS," the crew complete their stroke and hold their oars, feathered, at right angles to the boat. With proficient men this caution may be omitted.

STAND BY TO TOSS OARS— TOSS OARS. For the purpose of saluting, &c., the oars are tossed by bearing down on the handles with the inner hand with a jerk, so as to spring the blades of the oars up smartly to the position of *Toss*, assisted by the outer hand. Oars are not tossed in boats fitted with crutches.

Coming alongside a ship or landing on shore.

BOWS. Bowmen toss oars together and lay them in, and stand up in the bow of the boat with their boathooks vertically in front of them, ready to fend off, each man of the crew puts over his fender with his outer hand, continuing to row with the other.

In coming alongside a ship or landing, the coxswain gives the command in sufficient time to allow the bowmen to get their boathooks ready before they are alongside.

WAY ENOUGH. This command is given when the coxswain sees there is sufficient way on the boat; the crew finish their stroke and row one more, the

Up. port stroke then gives the word "*Up*," and all toss their oars. All but the crew are then ordered to "FILE OUT."

LAY IN YOUR OARS. The oars are laid, blades forward, between the men and their own side in a double-banked boat, and in the middle of it in a single-banked boat. To do this, the men keep their seats, but look towards the bow over their shoulders, as they lay them in quietly. The stroke oar next the landing stands with his boathook to hold the boat to.

Should there be a rough sea on when the boat is alongside a ship or landing, the men sitting nearest will assist in keeping the boat from knocking against it.

With crews under instruction, or in case of difficulty in reaching the landing, the coxswain, instead of giving the word "WAY ENOUGH," gives the caution, "STAND BY TO LAY ON YOUR OARS," followed by "OARS," "STAND BY TO TOSS OARS," "TOSS OARS," "LAY IN YOUR OARS." The men lay on their oars, toss oars, and lay in their oars as above described.

Gigs and boats with crutches coming alongside.

When gigs or boats with crutches come alongside, the oars will be managed as follows:—Bow oar will follow the orders given for cutters; the handle of each of the other oars is passed to the man on the next thwart forward, who hauls it through until the blade rests on its edge in the crutch, unless the oars are tied to the crutches, in which case they are allowed to swing. Occasionally the oars may have to be taken in and laid in the boat.

On leaving the boat each man returns the poppet into the rowlock, or takes the crutch in-board, as the case may be.

Boats are never to be left alongside a gangway, but as soon as the crew have got out the boatmen will drop the boat into her proper position. The tiller will always be taken out and laid in-board when the boat is not in use, and the back board and thole pins or crutches, if loose, will be removed.

Precautions to be taken.

5. The following precautions will be taken by all parties employed on the water:—

(1) In order to prevent injury, boats are always to be moved on shore on an *even keel*, and pontoons should be carried, not dragged.

(2) Cables, when on board, are always to be properly coiled (Part IIIA., Sec. IV., para. **25**) with the running ends on the tops of the coils, and the anchors laid clear of the coils; boats' anchors should be examined before starting, and when in the boat should be *unstocked*, and lying on the bottom forward, unless when likely to be wanted for immediate use.

(3) While rowing, the men are always to face the coxswain.

(4) While rowing to their moorings, or to any object with a view of making fast to it, boats or rafts must never run stem on with the current or wind (whichever be the stronger), but must reverse or change their direction, if necessary, in order to have the head of the boat or raft against the current (or wind) before they grapple with the object to which they are to make fast.

(5) When a large body of men is to be carried in boats they should all be told off in a column of boat parties, with the water on the directing flank. The crews being in their places, the boat-parties get the order to file in; each party forming single rank as it reaches its boat. The men should be made to sit down on the thwarts outside the rowers, so as to *trim* the boat, and if necessary *double man* the oars. No man is to sit on the gunwale, or on any occasion to stand up, unless ordered.

(6) In selecting anchorages, care should be taken to avoid casting the anchors among mooring chains, or other obstructions.

(7) Stores are not to be thrown ashore; everything should be handed or laid down carefully.

(8) Men are not to jump into the water without orders. Special men should be told off to perform any work in the water.

(9) When towing with more than one boat or raft the heaviest one is to be nearest the load, and a boat moderately loaded is better to tow with than one quite light. When a large boat tows a small one, any load is best carried in the former. The tow-line should be made fast to the sternmost ring on the kelson and not to the ring on the sternpost, and the towing boat can then be steered by pushing the tow-line over her quarter on the side to which it is wished to turn. Short tow-lines are generally best, and the boat in tow should also be steered. Rafts should be towed with two tow-lines. A boat taking another in tow, passes it, keeping her oars clear of the others, places herself right ahead in line, and gives way as soon as practicable after the painter or tow line has been passed from one to the other. A boat should not give another boat or raft her painter, until she is in line ahead of her, and special care must be taken to keep the two clear of each other, so as not to lose the power of rowing.

(10) Whenever a bridge is made across water a boat party will be told off to pick up men who fall in. In the case of wide or rapid rivers spars with buoyed lines attached should be moored about 300 yards below the bridge, and 150 yards apart. The buoyed lines afford a better chance of rescue to a man as he drifts past. Boats should be stationed below the spars to take the men off.

(11) Unless it is prejudicial to the tactical situation all floating bridges across water on which there is boat traffic should be well lighted.

When "cuts" are formed in floating bridges the cut-rafts, and each side of the cut, should be lighted.

The scheme of lighting should follow the local rules; but a good general scheme is to place a red light on each cut-raft and on each side of the cut, and station a patrol boat 200 yards above and below the bridge to warn masters of craft as they approach of the presence of the bridge.

6. The following are the rules for saluting to be observed in military boats :—*See* also K.R. Saluting.

(1) When an officer is in the boat—

Rank.	When passing.	Under oars.	Meeting at landing place or alongside ship.
Field Officers	Admiral or General	"Lay on Oars," Officer salutes.	Crew "Eyes Front," Officer and coxswain salute.
Field Officers	Other Naval and Military Officers, if senior.	Officer salutes.	Officer salutes.
Officers below rank of Field Officer.	Admiral or General	"Toss Oars," Officer salutes.	Crew "Eyes Front," Officer and coxswain salute.
Officers below rank of Field Officer.	Commodore ... Captain ... | Colonel ... Lieut.-Colonel	"Lay on Oars," Officer salutes.	Crew "Eyes Front," Officer and coxswain salute.
Officers below rank of Field Officer.	Other Officers of either Service whom they know to be senior.	Officer salutes.	Officer salutes.

(2) When no officer is in the boat—

When passing.	Under oars.	Meeting at landing place or alongside ship.
Admiral... ... Commodore ... Captain ... ... | General Officer Colonel ... Lieut.-Colonel	"Toss Oars," coxswain salutes.	Crew "Eyes Front," coxswain salutes.
All other Officers	"Lay on Oars," coxswain salutes.	Crew "Eyes Front," coxswain salutes.

NOTE.—In boats fitted with crutches, oars are never to be tossed, but the salute should be given by laying on oars.

(3) In steamboats, engines are to be stopped in those cases in which, in pulling boats, oars are tossed; engines are to be eased in those cases in which pulling boats "lay on" oars.

(4) Laden boats, or those towing or in tow, are not to toss or lay on their oars.

(5) Coxswains of boats under oars or sails, when an officer is in charge, only salute at landing places.

(6) Salutes in boats, under oars or sails, are to be made sitting down; in other cases standing up.

(7) Boats laying off on their oars are to salute as above, but the bowmen will salute as well as the coxswain.

(8) Boat keepers salute standing up in the ordinary manner.

(9) For a Royal Salute, the crew toss oars and stand up (in double banked boats only).

General principles of floating bridges.

General principles.

7. Floating bridges consist of a continuous roadway supported on piers of pontoons, boats, casks, &c. Each of these piers must have sufficient buoyancy to support the heaviest load that can come over it. The buoyancy of the various piers must be ascertained, and only part of the actual buoyancy can be taken as available, the margin allowed being greater in bridges over rough water or in those intended to remain in use for a long time. In calculating for *buoyancy* no allowance need be made for loads being live or moving instead of dead or stationary; but in calculating for *strength of road-bearers, &c.*, of course this allowance must be made.

Definitions.

8. The space from centre to centre of any two piers in a bridge is called a *bay*.

The side of the river from which a bridge is begun, or the side on which it is being dismantled, is called the *shore*; the end nearest the shore is called the *tail of the bridge*, and the bay connecting it with the shore is called the *shore bay*; the end of the bridge farthest from the shore is called the *head of the bridge*, and the bay that connects the head with the land is called the *landing bay*.

Length of piers.

9. For the sake of stability the piers should be twice as long as the roadway is wide, unless the buoyancy is much in excess of that required. They may often with advantage be connected together at their ends by tie-baulks or lashings (Pl. LXXXII.).

Clear waterway.

10. The clear waterway between two piers of a bridge constructed in a stream of over 4 miles an hour should not be less than the width of one pier.

Grounding of piers.

11. Casks bear grounding very well. A pier of 5 100-gall. casks has been tested when grounded on gravel bottom with a load of 12 tons with no apparent damage. Pontoons should not be allowed to ground under a load if it can be avoided, and then only on a smooth surface. Boats, unless flat bottomed, should not be allowed to ground with a weight on them.

Cuts.

12. *Cuts* are often required in a floating bridge to allow traffic to pass or to permit large floating objects, such as trees, to be guided through the bridge (para. **97**).

Swinging a bridge.

Sometimes the whole bridge or part of it may be swung by disconnecting a bay and allowing the shore ends to pivot freely on the banks. It is best to swing down stream, the piers at the stream ends being each supplied with one or more spare cables and heavy anchors if possible. The bridge can be brought back into position by hauling on the stream cables. Occasionally a central portion may be swung in mid-stream to form one or two channels.

13. The piers are connected by road-bearers, technically known as baulks, on which a roadway of chesses is laid. **General arrangement of floating bridges.**

If piers cannot float by the shore, or the number be insufficient, a causeway of trestles or fascines may be made out as far as required.

With different kinds of piers, any of the same kind, or those floating the same height out of the water, should be used together.

Piers in a tideless stream should be slightly down by the stern.

14. Roadways supported on saddle-beams are less stiff to resist the current, and require more support from anchors than those where the baulks overlap. In the latter case, also, the effect of a concentrated load is more distributed, but longer baulks are wanted, and in rough water the roadway is apt to be too rigid. **Roadway.**

In the absence of cleats on the saddle-beam, the depths of the baulks should not exceed twice their breadth, and this latter should be not less than 3 inches, in order to obviate the tendency to turn over, and also to have sufficient strength to resist any lateral stress.

The general arrangement of roadway is as described in Part IIIA., Sec. II., para. **4**.

The joints of the ribands and baulks should be over the centre of the pier, so as to allow play with uneven loads. With piers, not in themselves buoyant enough for the load of a gun, &c., the weight of the latter may be partly distributed on the adjacent piers, by using large ribands butting over the centre of the bays and continuous over the piers. Strong rack lashings should in such case be used over the piers. Whenever practical, handrails should be provided to floating bridges; these may be extemporised from surplus superstructure or material obtained locally. Screens to prevent the animals from seeing the water also tend to obviate accidents and consequent delays in crossing.

15. With very large piers, double roadways may be made of a width of 16 feet, or else of two single roads a foot or two apart. **Double roadways.**

16. When the materials for the bridge have been collected and sorted, and the ground in front has been occupied, if necessary, by a covering force, it is usual to set up pairs of banneroles on either bank to mark the alignment of the bridge, and of the up and down stream anchors. At night lanterns may be hung to these poles if the tactical conditions are not prejudiced by such action. **Alignments.**

17. After the construction of the bridge, a working party is constantly required to keep it in order and bail out the boats, barrels, &c., for which means must be provided. In floods, the cables must be continually watched, and slacked off, &c., as required. **Care of floating bridges.**

Guard boats should be sent up and down stream, and guards posted on islands or other convenient spots.

To prevent damage to the bridge from floating objects, booms either floating or fixed, or both, may be placed about 1,000 yards from the bridge. A strong chain or hawser, stretched across a stream and buoyed, if necessary, will check floating objects, or fire some kinds of torpedoes; but a boom formed of large logs chained together is a better obstacle. These floating booms should be oblique to the stream (20° with the banks); they require stream anchors, and their ends should be secured to land anchorages (Part IIIA., Sec. V., para. **13**). They must have play to rise and fall with the water.

Fixed obstacles may be made of groups of piles, with their heads tied together by rails spiked to them; groups of these may be used with floating booms between them.

Torpedoes, &c., have been intercepted by stretching strong nets (weigbted and buoyed) across the stream, or else wooden frames, resting against piles, and covered with wire netting. A light rope or wire stretched across a river can be made to pull a bell or fire a charge, so as to give an alarm. (Para. 70 and Sec. XVI.)

Anchors.

Use of anchors.

18. Anchors are required to counteract the effect of the current or wind on floating objects; the nature of holding ground, and the stress on the cables, regulate their size. To ensure holding (para. **25**), the length of the cables should be at least ten times the depth of the stream, with a minimum of 15 fathoms. When the length is less than three times the depth the anchors seldom hold. With pontoons it is usual to provide two to every second boat, one up and one down stream, the latter being chiefly to prevent oscillation and resist wind, except in tideways, where they act as up-stream anchors during the flood. In some cases each pier should have an up-stream anchor.

The weight of anchors required per foot run of pontoon bridge is roughly from 4 to 10 lbs.; cask and raft bridges give a heavier stress on cables than pontoons.

The pull due to any pier of a floating bridge may be approximately taken as Av^2 lbs.; where A = area of immersed section in square feet, and v = velocity of stream in feet per second.

Casting anchors.

19. Anchors are cast from boats, pontoons, or rafts. The operation of casting a pair of anchors is as follows, two men at least being required, and more if the anchors are very heavy:—The upper end of a coiled cable is secured to the ring of the first anchor by a fisherman's bend, and the anchor properly stocked and keyed, with a buoy and buoy-line bent on (Pl. II., Fig. 4). The lower end of this cable is then bent on to the upper end of the second coil by a sheet bend, and the lower end of the second cable bent to the second anchor by a fisherman's bend. The bend of the cables is then buoyed. This done, and the boat with stern way on, being over the position of the first stream anchor, one man heaves the anchor, grasping the shank close to the crown in the left hand, and the lower part of the shank in the right hand, and throwing it well away from him overboard, taking care not to foul the cable by standing on it. Both men then pay out the cable as it is drawn through their hands. The coxswain must be very careful to keep his boat in the direction of the position of the lower anchor. The men in the head of the boat throw the buoy overboard, and when about half of the second cable is overboard they hold on, as the boat should then be about over the line of lower anchors; the lower anchor is then cast, and the remainder of its cable thrown overboard. If, however, the stream be very strong, the cable may be kept on board and used for warping up to the line of stream anchors again. The other pairs of anchors are cast in the same way.

If the anchors are cast during the formation of the bridge, each cable is brought to the bridge as soon as its anchor is cast.

20. In strong streams, when laying up-stream anchors from a boat or raft, it is sometimes convenient to lay one above the line of up-stream anchors; by means of this the anchor-boat party can drop down stream to the bridge without fouling it, and after handing on a cable can haul up against stream each time it is about to lay another anchor, the down-stream boats or rafts being similarly helped by cables from the bridge. In large bridging operations, one or more reserve anchor boats or rafts should be kept ready moored up-stream.

21. Anchors are commonly raised by the buoy-line (or *tripping-line*), but it may sometimes be necessary to use the cable by hauling it in till the boat's bow is well down; the cable is then secured and the men move to the stern and force up the bow and with it the anchor. Weak boats will not, however, stand this.

22. When only few large anchors are available, the arrangements shown in Pl. II., Fig. 1 are sometimes convenient. Thus a single anchor at A holds two boats, at B three boats, at C four boats; the last two being only suited to slow currents and stiff roadways. At DE a raft anchored ready to form a cut is shown. In all cases the shore piers (Fig 3) are held into the bank by shore anchors or ties, not less than 30 yards to right and left of the bridge.

Substitutes for anchors.

23. In the absence of anchors, and with streams not over 100 yards wide, a hawser (Pl. II., Fig. 2) can be stretched across, buoyed with floats, and its ends secured to anchorages on each bank at a distance up-stream of about one-fourth the span; cables from the bridge piers are then secured to it; or these cables may each be secured ashore as far up (or down) stream as possible (Figs. 2 and 3). When the river is wider than the above, makeshift anchors may have to be used.

Makeshift anchors.

24. In bridging operations on a large scale, it is often necessary to improvise temporary anchors to moor the rafts, boats, &c.

An anchor may be made of two picks lashed together in two places, and two other pick-heads fitted over their ends, which are prevented from slipping off by two light lashings.

It is difficult to select picks that will fit firmly together for this anchor (Pl. II., Fig. 5).

Another anchor consists of one pick, the handle of which is rounded just below the head, and another pick-head driven on the handle at right angles to the first, and wedged there by driving in two spike nails. The holding power of this anchor is much increased by lashing sand-bags filled with stones to the head (Fig. 6). Any of the above anchors could be made by a couple of men in 15 minutes.

A cask, with six or eight projecting stakes run through holes bored diametrically near the bottom, and filled with stones, forms a good anchor, the cable being secured to the stakes inside the cask.

Rails or chairs from their weight answer instead of anchors; rails bent into the form of a grapnel are very powerful.

A form of wooden anchor which has been found useful is shown in Fig. 7, the crown being weighted with chains, &c.

Wicker anchors (inverted funnels) with a content of about 15 cubic feet, are found to hold well when filled with stones.

Another anchor (Fig. 8) that has been much used on rocky bottoms, consists of a cross formed of two pieces of wood 5 inches by 3 inches, and 3 feet long, halved into each other with the ends pointed. Into each arm 8 inches from the point a stake 6 feet long and 2 inches in diameter is wedged. In the framework thus formed heavy stones or shot are placed, sufficiently large not to slip out of the frame, and the four stakes are secured together at the top by two lashings.

A pair of wheels, lashed with their felloes together, and the space between the spokes filled with stones, makes a good holding anchor; or a stone with a ring for a cable is convenient. The cable should not be lashed round the stone as the edges are likely to fray the rope and cut it through in time.

A harrow loaded with stones, wooden cases, gabions, or nets filled with stones may also be resorted to; the latter have been found to hold on bottoms covered with boulders where nothing else held.

Holding power of anchors.

25. The following table shows the forces which were found to drag anchors of various kinds on a soft bottom:—

Description and Weight.	Extreme Holding Power.	Remarks.
	lbs.	
Common anchor, 112 lbs.	1,000	In good holding ground with cables at a slope of not more than $\frac{1}{10}$.
" " 56 "	600	
Martin's anchor, 72 "	480	
Common " 32 "	250	
" " 30 "	75	In indifferent holding ground.
Anchor of 4 picks, 30 "	70	
" 2 " 14 "	56	
" 2 " 60 " (weighted)	100	

The holding power of an anchor is greatly increased by laying out a small (or *kedge*) anchor beyond it as at F, Pl. II., Fig. 1.

Pontoon equipment.

26. The service pontoon equipment consists of pontoons, trestles, and superstructure carried on special wagons. Each wagon carries one to two bays (15 to 30 feet) of superstructure, and either a pontoon or 2 trestles. **Pontoon equipment.**

27. Each pontoon (Mark II) is carried on one wagon (Pl. III.), and consists of two sections, viz., a bow-piece and a stern-piece, which under normal conditions, whether on the wagon or in bridge, are coupled together by couplings of phosphor-bronze of the form shown in Pl. V. Each section weighs about 5 cwt. (Pl. V., Figs. 1, 2, 6, and 7). **Pontoon.**

Bow-piece—The length of the bow-piece is 11 feet 6 inches. It consists of two sets of framed ribs, connected by a kelson 6 inches deep; two side streaks $2\frac{1}{4}'' \times \frac{7}{8}''$; two gunwale pieces $3'' \times 2''$; and three bottom streaks $2\frac{1}{4}'' \times \frac{5}{8}''$. The square end is a framework consisting of a gunwale $4'' \times 3\frac{1}{2}''$, which carries the upper joints; one bottom piece $2\frac{1}{2}'' \times 2''$; and one intermediate streak $2\frac{1}{2}'' \times \frac{7}{8}''$. There is an anchor thwart in the bow end $3\frac{1}{2}'' \times 2''$, supported by diagonal pieces on each side $3\frac{1}{2}'' \times 2''$. The breadth of the section is 5 feet 3 inches, tapering to 2 feet 6 inches at the bows; the taper commences from the first thwart. The thwarts are placed over the framed ribs. The depth is 2 feet 5 inches from the square end to the first thwart and the gunwale rises from the first thwart to a height of 4 inches at the bow end. The sides and bottoms are of yellow pine, $\frac{3}{8}$ inch and $\frac{7}{16}$ inch thick respectively, with canvas secured to both surfaces by three layers of indiarubber solution on each side. The outer canvas is coated outside with two coats of marine glue. An iron ring is attached to the framework at the bows, and connected to the kelson by an iron strap. There is a wooden cleat for securing the cables on the top of the anchor thwart, and a cleat of 1-inch iron at the centre of the gunwale at the square end. On each side of the boat there is a side rail, to which are secured four handles, by which the pontoon can be carried by hand. The saddle beam (para. **29**) is secured by iron hinges fixed to the thwarts. The section is provided with 8 rowlocks, 3 on each side, and 1 at each end (Pl. V., Fig. 1).

Stern-piece.—The stern-piece is similar to the bow-piece, except that it is 9 feet 6 inches long, and has two square ends similar to the square end of the bow-piece. There is an iron cable cleat at each end. Eight rowlocks are provided: three on each side, and one at each end (Pl. V., Fig. 6).

28. The superstructure (Pl. VI.) consists of *baulks, button baulks, chesses, shore transoms,* and *ribands,* and for pontoons a *saddle-beam* for each section. For special purposes also *cut-baulks, cut-baulk saddles, shore-baulks,* are carried. **Superstructure.**

29. The saddle-beam (Fig. 5) is hollow, and one length can be fitted into another, so as to form a continuous saddle of any length that may be required. **Saddle-beam.**

Each part of the saddle-beam has four sets of curved cleats $8\frac{1}{2}'' \times 2\frac{1}{2}''$ at equal distances to receive the ends of the baulks. There are three other sets of cleats with square ends placed intermediately to receive the ends of the additional baulks necessary for the construction of a heavy bridge. The saddle-beam is of yellow deal, the cleats of ash; each part weighs 64 pounds.

Baulks. **30.** The service pattern baulk is made of Oregon pine; its length is 15 feet $9\frac{3}{4}$ inches, width at centre $3\frac{1}{4}$ inches, at ends $1\frac{1}{2}$ inches, depth 6 inches; the sides are hollowed for lightness; the ends are strengthened with iron plates top and bottom, the bottom plate is formed with two claws to prevent the baulk from slipping from its position on the saddle. Button baulks are similar to the above, except that they are fitted with 14 fixed buttons on the top, the first 1 foot $4\frac{1}{2}$ inches from the end, and the remainder 12 inches from centre to centre. These buttons prevent the chesses from moving forward or sideways.

Button baulks can only be used as the outside baulks of a roadway, and then only when properly cut chesses are used. The weight of a baulk is about 60 lbs.

Cut-baulks, cut-baulk saddles, and shore-baulks are shown on Pl. VII., Figs. 1, 2, and 3.

Shore transom. **31.** The shore transom for use at the end of a bridge is shown on Pl. VI., Fig. 6.

Chesses. **32.** The chesses (Fig. 4) are single planks of Canada red or Kauri pine, the length being 10 feet, the breadth 1 foot, and the depth $1\frac{1}{2}$ inches: the breadth at each end is diminished to enable the rack lashing to be passed between two adjoining chesses. Chesses weigh 45 lbs. each; they are not painted.

Ribands. **33.** The riband is made of Oregon pine, its dimensions are $15'\ 9'' \times 3\frac{1}{4}'' \times 6''$; it is halved at each end, and painted alternately black and white at every foot of length from the centre. They weigh about 60 lbs. (Pl. VI., Fig. 3).

Ribands can be used as baulks, as in heavy bridge (para. **109**).

Buoyancy. **34.** Pl. V., Figs. 11 and 12, show the immersion of the pontoon under ordinary loads. The following table shows its flotation power:—

BUOYANCY OF PONTOON MARK II WITH FREEBOARD FOR GIVEN LOADS.

Freeboard in inches.	Weight exclusive of superstructure which the bridges below will carry.			Remarks.
	Light.	Medium.	Heavy.	
	lbs.	lbs.	lbs.	
15	2,163	4,632	6,795	* 5 baulks only, if more are used add 60 lbs. for each baulk.
12	2,954	6,050	9,034	
9	3,609	7,658	11,267	
6	4,341	9,088	13,429	† Double chessed with 14 baulks.
Weight of superstructure.	720 for 15′ bay.	1,240* for 15′ bay.	1,200† for 7′ 6″ bay.	

Minimum freeboard in rough water is 12 inches, and in still water 6 inches.

35. The following are the weights brought upon a 15-foot bay :— *Loads on a 15-ft. bay.*

	lbs.
Armed infantry in single file crowded	2,100
" in file, proper intervals ...	2,400
" " crowded	4,200
" in fours, proper intervals ...	4,800
" " crowded	8,400
Cavalry, single file	2,950
" ½ sections	5,900
Cattle, crowded	6,750
Loaded camels in file and bullocks 2 abreast ...	3,500
Elephant, loaded	8,000
6″ howitzer on field carriage, and horsed and crowded	12,700
60-pr. gun...	12,100
4·7-inch gun	11,300
18-pr. gun...	5,086
13-pr. gun...	4,498
5-inch howitzer	6,600

*The service trestle.**

36. The service trestle* (Pls. VIII. and IX.) is carried in the field by R.E. field companies and bridging trains, on a special wagon called a trestle wagon (Pl. IV). *Service trestle.*

* Vocabulary nomenclature "Trestle, Bridging."

Transom.

37. The transom (Pl. IX., Figs. 13 and 14), is 13 feet 2 inches long, 12 inches deep, and 4 inches wide. In order to give the necessary width of timber to fit the claws of the haulks (8 inches) 2″ × 4″ fillets are fixed on either side flush with the top edge. The ends of the transom are bound with iron collars leaving an eighth of an inch of wood projecting beyond the iron. The transom is bored to receive the bolts of the grip-strap, and these holes are metal lined. Ringbolts for the hook of the differential tackles are provided at each end of the transom. These bolts pass right through the transom and are fitted at their lower ends with turnbuckles. The transom is made of Oregon pine and weighs 175 lbs.

Legs.

38. The legs are 16 feet 3 inches long and of 9″ × $3\frac{3}{4}$″ scantling. The foot of each leg is cut to form a tenon which fits into a hole cut in the shoe to receive it. The legs are made of Oregon pine. Each leg weighs 108 lbs.

Shoes.

39. The shoes are of pressed steel, and are attached to the feet by pins passing through the tenons. They measure 1′ 3″ × 2′ 0″ and are pressed from $\frac{3}{16}$-inch steel, and weigh 42 lbs. per pair.

Brackets.

40. With each trestle is also provided a pair of brackets, by means of which tackles may be suspended from the legs. Each bracket consists of two plates and three bolts. (Pl. IX., Fig. 11). They weigh 37 lbs. per pair.

Differential tackles.

41. Differential tackles are used with the trestle. These are hung from the brackets fixed at, or near, the head of the legs and hook into the ring bolts on the transom.

These tackles take the weight of the transom while it is being raised or lowered. They weigh 78 and 162 lbs. each respectively in the $\frac{1}{2}$-ton and 1-ton patterns. The principle on which they act is described in Part IIIA., Sec. V., para. **7**.

Bolts.

42. Bolts throughout are made of 1-inch round iron.

Lever straps.

43. In order to keep the legs at right angles to the transom while the trestle is being moved or adjusted, and to brace the structure generally while it is in use, two lever straps are provided. (Pl. VIII., Figs. 1 and 2.)

Each lever strap consists of two iron plates connected together with four bolts. The leg passes between the two upper, and the transom between the two lower bolts. The four bolts are so spaced that when the lower bolts are touching the transom above and below, the upper bolts do not touch the leg until the capstan-headed screw is tightened up. All the bolts are fitted with bearing plates and the upper one is fitted with a capstan-headed screw by means of which the strap can be made to grip the leg firmly and thus brace the trestle. The lever straps are not designed to take any of the load on the transom.

Each pair of lever straps weighs 120 lbs.

Pl. VIIIA illustrates an improved pattern of lever strap which is to be introduced. It braces the trestle in all positions, and the structure is, therefore, under better control. The weight of each strap is 78 lbs.

44. The transom and its load are supported by the grip straps. Each grip strap is provided with an outer bolt "A" fitted with a bearing plate, which bears against the outer face of one of the legs, and a pivot bolt "B" which passes through the transom. (Pl. VIII., Fig. 4.) Grip straps.

A pair of grip straps weighs $51\frac{1}{2}$ lbs. The action is as follows :—

The weight of the transom, while the grip straps are being adjusted, may be supported by tackles suspended from the heads of the legs by means of brackets. If, now, the outer ends of the grip straps are raised as high as possible and the butterfly nuts on the outer bolts "A" are tightened, so that the straps grip the outside edges of the legs, and the weight of the transom is allowed to come on the grip straps, the pull on the pivot bolt "B" transmitted through the straps will cause the legs to be jammed firmly against the ends of the transom. A very powerful frictional grip is thus obtained, and this grip has been tested up to 12 tons distributed over the transom without failure of any part.

45. The grip strap is used in three positions :— Positions.

(1) To support the load. In this case the outer ends of the grip straps are raised as much as possible, and the butterfly nut "A" is tightened up. (Pl. VIII., Fig. 4.)

(2) To adjust the transom. In this case the butterfly nut is loosened and the grip strap is allowed to assume a horizontal position resting on the turnbutton "C" at the lower end of the ring bolt. (Pl. VIII., Fig. 5.)

When adjusting the transom, the edge of the bearing plate must not be allowed to engage with the face of the leg, otherwise the straps will jam.

(3) To carry the trestle. In this case the outer ends of the grip strap are forced well down, and the butterfly nut tightened up. The grip straps are thus made to act as braces and assist the lever straps to prevent any distortion of the trestles. (Pl. VIII., Fig. 6.)

46. To adjust the transom. Take the weight with the tackles and ease the butterfly nuts of the grip straps, allowing the grip straps to drop to a horizontal position resting on the turnbutton; unscrew the capstan-headed screw of the lever straps. Adjusting the transom.

The transom can now be raised or lowered freely.

When in the required position raise the grip straps as high as possible, tighten up the butterfly nuts, ease off the tackles and allow the grip straps to take the weight.

After adjusting the transom and paying out the tackles, jump a few times on the transom to make sure that the grip straps have taken the weight.

Tighten up the capstan-headed screws of the lever straps.

Use of ledger.

47. On a treacherous or muddy bottom (and for launching with ways) it is necessary to use a ledger with the trestle. Without this precaution the legs are liable to splay while the transom is being adjusted, and it may be impossible to get them vertical again. The ledger does not form part of the equipment but can be extemporized from any plank or spar. It should have shallow notches to fit the legs and be lightly lashed to them, so that if one leg sinks lower than the other it can slide through the ledger lashing. (Pl. VIII., Fig. 1.)

Special instructions.

48. Under no circumstances may the lever straps grip the legs or transoms. The greatest care must be taken to ensure that the grip straps never grip the transom, and grip the legs only on their outer edges when the wing nuts are tightened.

If the lever straps grip the legs of the transom, it is impossible to know that the grip straps have taken the weight after the transom has been adjusted, and the trestle may collapse under the load. If the grip straps grip the face of the transom tightly they interfere with the self adjustment of the frictional grip.

The only bolts which should ever be screwed up tight are the outer bolts of the grip straps which have butterfly nuts, and to obviate mistake, the threads of the other bolts should be cut only so far that when the nuts are screwed home there may still be some play between the straps and the timber.

When working on a bad bottom with the ledger, if one leg of the trestle drops into a hole when the trestle is braced both legs will probably cant over but remain parallel. In this case the grip straps at the lower end of the transom may be dropped to the horizontal position, and the transom adjusted with the tackle, when both legs will return to the vertical. If there is no ledger, the legs will probably be slewed. In this case they can sometimes be straightened by lifting the lower end of the transom while the grip straps are down in the lowest position. This may not be possible if the legs are in deep mud, and in such a case the best remedy will probably be to take the trestle out of the bridge. Such a slip should never occur if the trestle is properly handled.

Placing trestles.

49. On a dry bottom or in shallow water, trestles can best be placed by hand; in deep water by means of ways or from a raft.

Service trestles are put together on the bank, the transom being adjusted to a convenient height, the grip straps being in the third or bracing position.

Twelve men will be required to carry a trestle on sound ground. Soft mud renders the work more difficult and as many as twenty men may be required.

The simplest method of placing or raising a trestle, after the first, on a dry bottom or shallow water, is to carry out the trestle and place it in line with the bridge with its feet in almost the desired position but with the heads of the legs pointing away from the shore. The tackles of the last trestle in the bridge are then employed to haul up the head of the trestle while the feet are prevented from sliding by men with handspikes and with foot ropes. The tackles may be connected to lashings to get the requisite length. When nearly vertical, the two outside baulks are placed on the transom and in their proper cleats, the inshore jaws of the baulks being guided into their proper position as the trestle becomes vertical.

In deep water the use of a ledger and ways, as described in Section X, para. **7**, is probably the simplest method of launching from the shore. The trestles may be floated out to avoid carrying, in which case the tackles and brackets should not be added till the trestle is in position.

If pontoons and their equipment are available, several trestles already made up into a bridge complete with superstructure can be launched simultaneously. This method of placing has very distinct advantages in tidal waters and is quicker and less laborious than any other method. The pontoons are at a proper state of tide warped to a convenient site and formed into medium bridge with five baulks, but without chesses. One more pontoon than trestle will be required. The trestles are then put together, carried to the pontoons and placed astride of the baulks. Ledgers if required can now be lashed to the legs below the baulks, by leaning the trestles over a sufficient distance to bring the feet within reach of men on the pontoon baulks. The trestles are then brought into a vertical position resting on their transom, with their feet and shoes clear of the bottom. The baulks and the chesses for the trestle bridge can now be added. The whole raft can then be warped into the required position of the bridge. The grip straps are then loosened, and the legs are allowed to slide down to the bottom. When they have taken their bearing the tackles are employed to raise the transoms clear of the pontoon baulks; these are now removed and placed in the pontoons, which are sent back to the shore.

The reverse of this process may often be employed in dismantling a trestle bridge.

A single trestle may also be launched from one pontoon from which the saddle beam has been removed, by placing it astride, resting on its transom on the gunwales.

50. A trestle bridge is completed finally by tying the heads and feet of adjacent trestles together as follows:— *Completion of a trestle bridge.*

The foot ropes are passed through the holes in the legs of the trestles made for the purpose, and a clove hitch is made in the centre of the rope round the leg. A bowline is then made at each end of the foot ropes. A clove hitch is now made in the centre of the head ropes round the top of the leg, and each end is then passed through the bowlines of the foot ropes of the adjacent trestles and made fast with two half-hitches. (Pl. XXVII., Figs. 1 and 2.)

51. TABLE OF PONTOON EQUIPMENT CARRIED IN THE FIELD.

Articles.		A bridging train.	A field company.	
Section 8A.				
Cordage, hemp hawser, 3 strand, tarred	3-in. fms.	2,520	60	For cables 30 fms.
	$1\frac{1}{2}$-in. fms.	2,000	100	For breast-lines 60 ft.
Section 8B.				
Lifebuoys		4	—	
Oars, ash, leathered, 12 ft.		210	10	
Section 19.				
Tackles, differential, 10 cwt.		32	4	For trestles.
Section 29C.				
Anchors	boat, 1 cwt....	20	—	
	pontoon, ½ cwt.	42	2	
Bailers, pontoon		42	2	
Baulks	Mark III	250	15	
	Mark III Half	14	—	
	button	100	10	
	button Half	2	—	
	cut	32	—	
	shore end inside, Mark II sets	10	2	
	shore end outside ... sets	10	2	
Beams, saddle, Mark II		42	2	
Boat hooks, 11 ft. 7½ in.		42	2	
Bolts, ⅝ in diam. 13 in. long, with 1½ in. cheese heads		150	—	
Buoys, anchor, iron		84	2	
Chesses, Mark II		900	81	
Pontoons, bipartite	Mark II ...	42	2	
	battens	16	—	
	ribs	16	—	
Ribands		100	10	
Saddles, baulk cut		14	—	
Sticks, rack		350	27	
Transoms, shore end, Mark III ...		10	2	
Trestles, bridging, without tackles, differential		16	2	

Use of pontoons.

Use of Pontoons.

52. The pontoons can be used in light, medium, or heavy bridge:—

(*a*) In *light bridge* (for infantry in file) each section is used separately, and the superstructure so arranged that a length of bridge, double that when normal boats are used, can be obtained. (Pl. VII., Fig. 4.)

(*b*) In *medium bridge*, which is the normal bridge, the two sections are joined together. As a rule, five baulks only are employed for each bay in this bridge, though nine may be necessary to support the chesses under specially concentrated loads, such as gun-wheels, elephants, &c. (Pl. VII., Fig. 5.)

(*c*) In *heavy bridge* the piers are formed as in medium bridge and are placed 7 feet 6 inches interval from centre to centre, 14 baulks being used. (Pl. XI.). This bridge is designed to carry a light tractor weighing 7½ tons with 5 tons on the rear axle and a wheel base of 7 feet 6 inches.

53. Two sections, when coupled together, are easy to row, both as boats and in rafts, the lines of the bow being designed so as to reduce the resistance of the water. By joining two pontoons together, a boat of 12 oars is obtained. In the same way, by joining two rafts of normal boats together, eight men can row, and thus rafts can be rowed against a fairly strong wind and tide. Pontoons used as boats or rafts.

54. By coupling together two bow pieces a very handy boat is formed for use when it has to frequently change direction, as when laying anchors.

55. Two pontoons can be joined stern to stern and a double roadway formed. Double road-way.

56. The different ways of constructing bridges with pontoons are:— Methods of forming bridge.

(*a*) By *Forming up* or connecting the pontoons in succession at the head of the bridge, the reverse operation being *Dismantling*. (Pls. XIII. and XIV.)

(*b*) By *Rafts*, or making rafts of two or more pontoons, moving them into position, and connecting them into bridge simultaneously or in succession, the reverse operation being *Breaking up into Rafts*. (Pls. XV. and XVI.)

(*c*) By *Swinging*, or making bridge alongside the shore and swinging across the river. Bridge can be swung back in the same way. (Pl. XVII.)

(*d*) By *Booming out*, or connecting the pontoons with the superstructure in succession from the shore, and pushing or booming out until the head of the bridge reaches the opposite bank; the reverse operation is *booming in*. This method is only occasionally used.

(*a*) When making a bridge by forming up, it is advisable that the unpacking and the forming up should proceed simultaneously; it is therefore necessary that there should be sufficient men to unpack two wagons at a time at first, but when about half the bridge has been made, one of the unpacking (or wagon) sections can be detailed for other work, such as carrying the superstructure to the head of the bridge, or making up the ends of the bridge, improving approaches, &c.

(*b*) Occasionally it is necessary to make a bridge from rafts, which may either be put together near the spot where the bridge is to be, or at some other part of the river, from whence they may be rowed to the site of the bridge, and connected into bridge either in succession or simultaneously.

(*c*) By this method troops can be thrown across a river very rapidly, as they may be placed on the bridge before it is swung, and immediately the head of the bridge reaches the opposite bank the troops can be thrown ashore. If secrecy is desired, this bridge can be made under cover of a salient of the bank or an island, and there dropped down stream and swung across.

(*d*) In booming out, any spare men from tbe unpacking party may assist at the cables.

Light bridging equipment.

Light bridging equipment.

57. The Light Bridging Equipment in use in the service is of two kinds :—

1. Air raft equipment, issued to the cavalry.
2. Light raft equipment, issued to the field troops, R.E.

Besides these, the field company in Egypt is provided with an air raft equipment specially designed for camel transport.

Air raft equipment.

Stores.

58. Stores required for an air raft are as follows :—

Bags, inner, rubber	60
Bags, outer, canvas...	60
Baulk-saddles hinged with grummets ...	6
Boats, canvas, 10 feet, collapsible, with two valises; oars, jointed, in two pieces; paint, flexible; and repair outfit in holdall	1
Pumps, air, foot, with one length of hose, 4 feet...	1
Wheel-ways, shore, with scotch	2
Wheel-ways, raft, in two pieces (A and B) ...	2

The following is also carried for use with the raft :—

Cordage, hemp, hawser, 3-strand, white, 2-inch, in lengths of 70 fathoms.	2

These are illustrated on Pls. XX., XXI. and XXII.

Description.

59. Air-bags: Each is composed of an outer canvas case with an inner rubber lining; are strapped in groups of twelve on to hinged baulk-saddles, thus making five piers. One spare baulk-saddle is carried in case of breakage.

These five piers are connected into one raft by two raft wheel-ways.

Wheel-ways: Each is composed of two pieces locking into one another at the centre.

For use with the raft there are two *shore wheel-ways*, which can be placed, by means of two scotches, at any point of the raft wheel-ways, thus making connection with the shore. These shore wheel-ways are not permanently connected to the raft.

The loaded raft is hauled backwards and forwards across the river by two *tow lines* of 2-inch cordage, each 70 fathoms long.

For inflating the bags, two *foot pumps* are carried, with four lengths of indiarubber *hose* (two spare).

For getting one tow-line to the far bank and also for general use, a small *collapsible boat* is carried in two valises.

60. On arrival at the site, the wagon is unpacked, the collapsible boat is put together and tow-lines laid out. One tow-line can be taken across the river, with a suitable party for working it, by means of the boat. **Construction of the raft.**

The air-bags, which should be carried with the inner lining in place inside the canvas cover, are inflated. If time presses, the first part of the inflation can be done by mouth, the bags being brought to their final pressure by the pumps. The pressure of inflation should be about that of a football.

The five piers are each made by tying twelve of the inflated bags close together side by side, by the strings attached to the sides of the outer covers; the bottom strings should be tied first and the row of bags then turned over and the upper strings tied. The valve of each bag should be at the same side of the pier. Each row of bags is then strapped to a baulk-saddle by the webbing straps on the outer covers. The baulk-saddles are placed so that the hinge is downwards, and between the 6th and 7th bags. No straps should be placed in the spaces between the cleats on the baulk-saddles.

The five piers are now laid in parallel lines and the raft wheel-ways, which should have been previously locked together laid on them, in the spaces between the cleats on the baulk-saddles. The raft wheel-ways can be prevented from coming unlocked, during the construction of the raft, by securing the two halves temporarily, by the lashings attached to their cleats at the joints. The joints in the wheel-ways should be over the centre pier and the other piers should be under the remaining cleats on the wheel-ways.

The raft wheel-ways are secured to the baulk-saddles by the lashings on the wheel-way cleats, which should make a round turn round the baulk saddle, and then be secured to their own cleats. For the centre pier, the lashings from each half wheel-way are taken round the centre baulk-saddle, with a round turn, and secured to their own cleat.

The raft may be further consolidated by tying the piers together by the strings at the ends of the outer covers.

The raft is now launched into the river, by lifting it by the grummets at the ends of the baulk-saddles; the two tow lines are made fast to opposite ends of the raft.

The shore wheel-ways and scotches can now be placed in position for loading the raft.

Use of air raft.

61. The raft is designed to carry vehicles. It will not carry horses, and it is not very suitable for carrying men or saddles, as there is no decking. If it is required to utilize it for this last purpose, planking should be obtained locally and laid across the baulk-saddles, parallel to the raft wheel-ways.

The raft will carry any limbered vehicle with a cavalry division, including R.H.A. guns and R.E. tool carts. Its flotation is insufficient, and its design is unsuitable, for carrying loaded G.S. wagons, or other four-wheeled vehicles.

The vehicle to be loaded on to the raft is unlimbered, and the raft brought near the shore, with the raft wheel-ways at right angles to the bank. The scotches are then placed on the raft wheel-ways, and, if the depth of water at the bank will allow, about one-third of the way across the raft. The shore wheel-ways are now placed in position, the ends with the knuckle joints fitting into the scotches. If the river bank is too high, it must be cut down.

The first half of the limbered vehicle is now run on to the raft and scotched with stones or other improvised wedges.

The shore wheel-ways are now removed, the scotches brought back to the end of the raft wheel-ways nearer the bank and the shore wheel-ways replaced. The knuckle joints on the shore wheel-ways can be placed directly on the ends of the raft wheel-ways, if required.

The second half of the limbered vehicle is then run on to the raft and scotched. The shore wheel-ways and scotches are removed and laid on the raft, which is then towed across the river. The process of unloading the raft at the far shore is the reverse of loading.

The vehicles should be loaded with their perches or poles inwards. A short piece of plank should be used to prevent injury to the bags by the trail or perch of the portion first placed on the raft, and the pole of the second portion should be placed upwards. Men must take care not to injure the bags by treading on them when loading and unloading the raft.

Light raft equipment.

Light raft equipment.

62. This equipment, which is issued to a Field Squadron R.E., is designed to accompany cavalry and horse artillery, and is capable of carrying any horse vehicle with a cavalry division. It is carried in six-horse "boat-wagons." Each "boat-wagon" contains the following articles, forming one complete raft with a shore bay:—

Article.	Amount.	Weight (each).	Total Weight.
		lbs.	lbs.
Boats, collapsible, bow sections A	1	174	174
" " " " B	1	174	174
" " stern "	4	200	800
Oars, with rowlocks	12	$6\frac{1}{2}$	78
Platforms	1	112	112
Anchors, boat	1	46	46
Scotches { ramp	2	$6\frac{1}{2}$	13
Scotches { wheel	4	7	28
Skids { ramp	2	$81\frac{1}{2}$	163
Skids { wheel	2	84	168
Buoys, cork	1	15	15
Rope, steel, ·65″	200 yards	132	132

Besides this boat equipment, the "boat-wagon" contains axes, mauls, pickets, lashings, &c. The total weight behind the team is nearly 4,000 lbs.

63. Each section of boat can be opened by two men, and two men can also construct a raft, although it is better to employ six. The boats are locked open by the insertion of the seat planks, which are fastened to the sides by a slot and key. Once in the water, the pressure tends to keep them open. Construction of raft.

The sections are connected by means of pins and eyes at the keel and steel screw-locks at each side on the gunwale.

The seats are placed so that six men can row and two to steer the loaded raft. (Pl. XXIV., Fig. 1.)

The raft skids, supplied with a semi-cylindrical projection on the bottom of each end, are held fast by insertion of this projection into a similarly shaped slot in the sliding block. (Pl. XXIII., Fig. 1).

Two rafts or more can be connected into bridge by using the ramp skids to join the respective rafts, an extra pair being required to form the landing bay.

This will enable unhorsed wagons, &c., to cross, but planking is required to supplement the platform for the passage of infantry.

If horses are required to cross the bridge, they can do so in single file by improvising a roadway between the skids, out of baulks and planking.

Drill with service equipment.

64. The drill in the following pages has been prepared to show how the pontoon equipment may be most expeditiously Drill with pontoons.

manipulated through the various stages of bridge construction from the arrival of the bridging wagons at or near the site of the bridge to the actual completion of the bridge by one of the methods mentioned in para. **56**; and *vice versâ*, from the dismantling of the bridge to the repacking of the equipment on the wagons.

The numbers given in the tables are those normally required.

Drill with untrained men.

65. On active service, or even during peace training, it will frequently happen that the men available are either not fully trained or not trained at all, and that the time at disposal is too short to admit of the drill being taught. In these circumstances the drill must be modified to suit the circumstances, on the lines suggested in paras. **103** and **104**, but in order that the work may progress smoothly it is essential that the officers and non-commissioned officers have a thorough knowledge of the drill by numbers, so that the various detachments may be under efficient control, and that there is no overlapping of duties and consequent confusion.

Very satisfactory results have been obtained by parties of untrained men working under the direction of properly qualified officers and non-commissioned officers.

Organization of pontooning parties.

66. For bridging operations the unit is the detachment, consisting of one non-commissioned officer and seven men.

Two detachments form one section.

Four detachments form one wagon division.

Six detachments form one bridging division.

One detachment can man one pontoon or one raft.

One section can pack or unpack a wagon.

One bridge division can make a bridge in an ordinary stream when the wagons have been unpacked.

Table A shows the detail of men required for unpacking and "forming up" bridge simultaneously. The numbers of the spare division may be modified according to the numbers of pontoons, cables, &c., required. The detail of manning rafts is also shown.

TABLE A.

Divisions and Sections.			N.C.Os.	Men.	Detail of manning rafts of bridge 100 yards long. From one bank. No. of Raft.	From two banks. First 50 yards of bridge. No. of Raft.	From two banks. Second 50 yards of bridge. No. of Raft.
No. 1 (or Wagon) Division	No. 1 (wagon) Section.	A	1	7	1	1	—
		B	1	7	2	2	—
	No. 2 (wagon) Section.	A	1	7	3	3	—
		B	1	7	4	4	—
No. 2 (or Bridge) Division	No. 3 (bridge) Section.	E	1	7	5	—	1
		F	1	7	6	—	2
	No. 4 (bridge) Section.	G	1	7	7	—	3
		H	1	7	8	—	4
No. 3 (or Spare) Division	No. 5 (boat) Section.	I	1	7	Boat	Boat	Boat
		J	1	7	Boat	Boat	Boat
	No. 6 (spare) Section.	K	1	7	Spare	Spare	Spare
		L	1	7	Spare	Spare	Spare
			12	84	...	...	...

A bridge can be made by the following numbers in narrow still waters:—

—		N.C.O.	Men.	—
No. 1 (Wagon) Section	A	1	7	
	B	1	7	
No. 2 (Wagon) Section	A	1	7	This Section being available after about half the wagons are unpacked as a spare section.
	B	1	7	
No. 3 (Bridge) Section	E	1	7	
	F	1	7	
No. 4 (Bridge) Section	G	1	7	
	H	1	7	

67. The strength of the spare division will vary with the number of anchor boats required; the number of men necessary to man the cables will vary with the circumstances of the case.

68. When dismantling, the bridge division will bring in the stores quicker than the wagon division can pack up; a section of the spare division should therefore be told off as soon as possible as a wagon section.

69. The ordinary positions of officers are, one at the head of the bridge, one on shore at the tail of the bridge, one superintending the bringing up of the wagons, and one assisting the commanding officer in general superintendence.

70. When any bridge is completed, the officer in charge will detail a non-commissioned officer and a working party of (probably) one man to each pontoon that is anchored, to attend to cables, make any necessary cut in the bridge, &c.; a party of similar strength should be told off as a relief; a guard will be mounted, and one or more sentries posted at each end of the bridge, which will always be in charge of an officer when troops are crossing. When the bridge is required for traffic any men actually working on the bridge must get into the nearest pontoon, leaving the roadway clear.

71. In the following pages each man is designated by the letter of his detachment, and by his number in the detachment; thus A 7. means No. 7 in A detachment, and F.C. means the commander of F detachment, S.3. means the commander of No. 3 Section.

The words of command printed in capitals are to be given by the officer in charge, and those in italics by the Section Commanders.

For instructional purposes the drill is taught in "quick time," but with well-trained men it should, as a rule, be done in "double time."

Unpacking and packing wagons.

Party for unpacking.

72. The party ordinarily required to unpack or pack one wagon consists of two detachments; the whole of the wagons cannot, therefore, be unpacked at the same time, but when it is necessary (as, for instance, when a bridge has to be made along the shore and then swung across a river) to unpack all the wagons before commencing to make the bridge, each unpacking section has to unpack four or five wagons, and the whole can thus be unpacked in 10 minutes with well-trained men.

Pls. III. and IV. show the packing of the equipment of a pontoon and trestle wagon for a Field Company R.E., according to the F.S. Manual, 1910. The packing of these wagons for a Bridging Train is slightly different—no superstructures being carried on the top of the pontoon, while the number of baulks on the pontoon wagon is reduced to 7, and the number of ribands on the trestle wagon is reduced to 2.

Owing to the pontoon being made in two sections, it is possible, when short of men, for one detachment to unpack a wagon, the sections being uncoupled and removed separately.

73. For unpacking, the wagons being drawn up (usually in line) at some convenient spot near at hand, two are detached and drawn up 10 yards apart and about 20 yards from the edge of the water, the rear of the wagons being towards the water, Commanders should be informed whether heavy anchors are required and whether the stores are to be laid out for rafting or swinging, or for forming up. If for the former, the baulks and ribands for the two bays will be placed parallel to the river bank, with the chesses in two piles on their right (facing the river); other stores in rear of the baulks and ribands. (Pl. XV., Figs. 1 and 2.) If the stores are required for forming up, the baulks and ribands will be placed at right angles to the bank on either side of the approach to the bridge, baulks on the inside and ribands outside the baulks. The chesses are placed in piles of 15 each, at right angles to the bank and outside the baulks and ribands. Other stores in rear of the baulks. (Pl. XIV.)

The Wagon Division, which should be in charge of an officer, falls in, in column of detachments, between the water and the wagons, having the wagons on the right, the commanders taking post on the river side of the detachments. Unpacking in quick time.

LETTER YOUR DETACHMENTS FROM THE REAR. The commanders take a pace to their front, turn towards their detachments, and letter them A; B; A; B. The latter afterwards act as E, F, spare detachments, if required.

SIZE AND NUMBER YOUR DETACHMENTS. The commanders size their detachments, tallest on the right, so that the tallest men shall be nearest the horses, and the shoulders of the men as level as possible, then number their detachments and fall in.

RIGHT TURN; FILE ON YOUR WAGONS; QUICK MARCH. The whole turn to the right, march to the wagons, and place themselves facing inwards as follows:—

A detachments, off (or right) side of their wagons.

B detachments, near (or left) side of their wagons.

Nos. 1 should be in line with the splinter bars of their wagons; Nos. 7 in line with the rear of the hind wheel; the remaining numbers dividing the distance between them. A.C. and B.C. march on their wagons with their detachments, and assist them to take off and carry away the pontoon.

The officer or N.C.O. at the tail of the bridge should show the place for stacking the chesses when brought from the wagons; he also directs where the baulks, ribands, and stores are to be placed. The detail for unpacking one or more wagons by A and B detachments is as follows:—

IN QUICK TIME UNPACK. The commanders put on the brake, unbolt the chess-securers, and take off anchors.

Nos. 1 stand to the heads of the wheel horses.

Nos. 2 and 7 get up into the pontoon, unlash the superstructure carried on the pontoon,* and hand down stores to Nos. 3 and 6, as follows :—

A.3. and A.6., two breastlines and one buoy and half the superstructure carried on the pontoon.*

B.3. and B.6., two cables and, if the heavy anchor is to be used, one buoy and buoyline and half the superstructure carried on the pontoon.*

The stores are placed behind the numbers who receive them about two yards from the wagon.

Nos. 4 and 5 unlash pontoon and secure the lashings to the hooks provided for the purpose.

On completion, all numbers fall-in opposite to the handles of the pontoon.

PREPARE TO SHOULDER. The men turn towards the rear of the wagon, the rear number on either side gets his shoulder under the pontoon; the remainder, including the commanders, take hold (with their outward hands) of the handles of the pontoon, and prepare to lift and push forward.

SHOULDER. The whole lift the pontoon, pushing it off the wagon, each number as he passes clear of the hind wheel of the wagon, placing his shoulder under the pontoon, which is carried straight to the spot for launching pontoons. Great care should be taken in teaching the men to move off together at the word "Shoulder"; with untrained men it is better to take the pontoon on the arms.

(A.C.) *Halt, Down.* On reaching the water's edge the detachments are halted; they shift the pontoon from their shoulders, lower it by the handles till it rests on the ground, taking care that the bottom of the pontoon is not injured by bumping the ground.

(A.C.) *Prepare to lift; lift; quick march; launch.* The detachments man the handles of the pontoon, lift it a few inches from the ground, and launch it, taking care to avoid rubbing the bottom against the ground; B.C. passing it to H.C. and H.1. bridge division.

The detachments double back to the wagon, and form up on their respective sides of it for carrying away baulks.

RIBANDS AND BAULKS. The numbers work in pairs on their own side of the wagon as follows: Nos. 1 and 7, 2 and 6, 3 and 5, while Nos. 4 of each

* Field companies only.

detachment work together, and in the order named remove ribands and baulks, always taking the riband or baulk nearest them, and double along in turn to the spot at which they are to be deposited. The whole then double back to the wagon, and form up as when first filed on the wagons, facing inwards.

CHESSES. The whole turn to the rear; A.1. and B.1. partly push out some of the upper chesses from the end next the horses; then every man of the two detachments, as well as A.C., takes a c ess in the hand nearest the wagon, and doubles away with it to the spot selected for the chesses by the officer or N.C.O. at the tail of the bridge. A.C. takes the first chess, then A.7. and B.7 the next two chesses, then A.6. and B.6. and so on.

To avoid crowding, A.C and B.C. will see that the men place the chesses in four piles.

As soon as all the chesses have been taken away, the detachments double back and form up as at first on the wagons, facing inwards.

STORES. A.6. takes an anchor and buoy, A.1. and A.7. take the 112-lb. anchor and buoy and buoyline when required. A.3. takes the two breast-lines, B.1. and B.7. the front cable, B.3. and B.6. the rear cable, the remaining numbers take away any other stores that may have been unloaded; all the stores are taken to the spot pointed out by the officer or N.C.O. at the tail of the bridge. A.C. sees that all stores are removed and ground cleared to allow wagons to drive away, fastens chess securers and reports "wagon all correct." The whole of the detachments fall in on their wagons as at first, facing inwards.

DETACHMENTS, REAR; RIGHT AND LEFT TURN; QUICK MARCH; HALT; FRONT; STAND AT EASE. The detachments move off and form up in column, B in front, on their original ground, but so as not to interfere with the advance of the next pair of wagons.

74. Unpacking in double time is done in the same way, the words of command being:— Unpacking in double time.

"RIGHT TURN"; "FILE ON YOUR WAGONS"; "DOUBLE MARCH"; "IN DOUBLE TIME UNPACK"; "PREPARE TO SHOULDER"; "SHOULDER"; "*Halt*"; "*Down*"; "*Prepare to lift*"; "*Lift*"; "*Quick March*"; "*Launch*"; "DETACHMENTS, REAR"; "RIGHT AND LEFT TURN"; "DOUBLE MARCH"; "HALT"; "RIGHT OR LEFT TURN."

"STAND EASY," but so as not to interfere with the advance of the next pair of wagons.

Immediately the two wagons have been unpacked, the officer in charge moves them away, and their places are at once filled by another pair of wagons. The operation is then repeated until enough stores have been unpacked.

75. If required, after a few of the wagons have been unpacked, two detachments may be sent away and become E and F bridge detachments (spare), and when the work of unpacking the wagons is completed, the wagon division is provided with picks and shovels, divided into two parties, and told off to make up the ends of the bridge.

76. The officer in charge of the wagon division should caution the men, if any of the wagon stores (such as heavy anchors,* &c.) are not to be unpacked.

Packing in quick time.

77. In packing, the wagon division is formed in column of detachments. Two empty wagons are brought up and halted at about 10 yards apart and 20 yards from where the pontoons, stores, &c., are to be brought ashore, the rear of the wagons being towards the water.

The detachments being lettered, sized, and numbered, are filed on their wagons as for unpacking. The officer or N.C.O. at the tail of the bridge directs where the pontoons should be brought ashore. The detail for packing one or more wagons by A and B detachments is as follows ;—

STORES. A.C. unbolts the chess securers, A.6. fetches an anchor and buoy (and A.1. and A.7. the 112-lb. anchor and buoy) and places them on the ground about two yards from the wagon. A.3. brings two breast-lines and places them on the ground about two yards from and opposite to the wheels of the wagon. B.1 and B.7., B. 3. and B.6., bring the two cables and place them about two yards from the wagon. Each number resumes his place directly his work is finished.

CHESSES. The men and A.C. bring one chess each, carrying them away in the opposite hand to that with which they carry them to the bridge. A.1. and B.1. at once place their chesses in the rack under the wagon, B.C. assisting them at the front end, then A.2. and B.2., and so on, A.C. placing the last chess in the rack. Each number except A.1. and B.1. (who, after placing their chesses, remain at the front end of the chess-rack to assist the other numbers in placing theirs), as soon as his chess is placed, resumes his position by the wagon.

* Each pontoon wagon carries a 56-lb. anchor, and in the Bridging Trains every alternate wagon a 112-lb anchor as well.

BAULKS AND RIBANDS.

The men, working in pairs as in unpacking, but in the reverse order bring and place the baulks and ribands which they removed. B.C. passes a breast-line through the ring of the pontoon to be brought up. Directly each pair of men have placed their baulk or riband on the wagon they double away to where the pontoons are and fall in, Nos. 1 on each side of the pontoon taking hold of the handles nearest its shore end, Nos. 2 next them; the other numbers man the breast-lines.

(A.C.) *Prepare to heave*; *Heave*.

Directly all the numbers have arrived, A.C. gives the words in the margin, when the numbers who have hold of the pontoon lift and heave the end of the pontoon on shore; the other numbers fall in in rotation as the pontoon comes ashore, the words "*Prepare to heave*," "*Heave*," being repeated as often as necessary by A.C. until the pontoon is out of the water.

When the banks of the river are steep and difficult a ramp should be made on completion of the bridge for getting the pontoons out of the water when dismantling, and if rollers are available they should be used. Neglect of this duty may lead to considerable delay in dismantling and packing the equipment.

(A.C.) *Prepare to lift*; *Lift*; *Quick march*.

The detachments lift the pontoon a few inches from the ground, step off together, and march on the wagon, A.C. directing their march so as to bring the pontoon in rear and in prolongation of its wagon, when he gives the words in the margin, and the men halt and lower the pontoon steadily on the ground.

Halt, down.

(A.C.) *Prepare to shoulder*; *Shoulder*; *Quick march*; *Steady*.

The detachments grasp the handles of the pontoon with their outer hands, lift it on to their shoulders, turning towards the wagon, and step off steadily.

As soon as they reach the wagon Nos. 1 lower the end of the pontoon on to the baulks and guide it into its place, the other numbers pushing it slowly on. A.C. runs to the front end of the wagon and gives the word "*Steady*" as soon as the pontoon reaches its place, and the whole of the numbers at once resume their position on the wagons, facing inwards.

LASH.

Nos. 1 stand to the heads of the wheel horses. The Commanders secure the anchors in their places on the wagon.

Nos. 2 and 7 get up into the pontoon and receive stores from Nos. 3 and 6 as follows:—

A.3. and A.6. hand up two breastlines and one buoy and half the superstructure carried on the pontoon.*

B.3. and B.6. hand up two cables and, if they have been unpacked, one buoy and buoyline and half the superstructure carried on the pontoon.*

Nos. 4 and 5 lash the pontoon to the wagon.

A.C. fastens chess-securers, looks round the wagon to see that all the stores are properly stored away, and then reports "Wagon all correct."

On completion of his work, each number resumes his original position.

DETACHMENTS, REAR; RIGHT AND LEFT TURN; QUICK MARCH; HALT; RIGHT (OR LEFT) TURN; STAND AT EASE.

The detachments, in accordance with the words of command, move off and form up in column on their original ground.

Packing in double time.

78. In packing in double time the work is done in the same way. The words of command are:— "RIGHT TURN"; "FILE ON YOUR WAGONS"; "DOUBLE MARCH"; "STORES"; "*Prepare to heave*"; "*Heave*"; "*Prepare to lift*"; "*Lift*"; "*Quick march*"; "*Halt*"; "*Down*"; "*Prepare to Shoulder*"; "*Shoulder*"; "*Quick march*"; "*Steady*"; "DETACHMENTS, REAR"; "RIGHT AND LEFT TURN"; "DOUBLE MARCH"; "HALT"; "RIGHT (OR LEFT) TURN"; "STAND AT EASE."

Immediately the packing of the two wagons is completed the officer in charge moves them away and fills their place with a pair of empty wagons. The operation of packing is then repeated until all the wagons are packed.

Unpacking and packing pontoons with untrained men.

79. The party should be told off into squads of one non-commissioned officer and 20 men, sized into two ranks. One squad should be formed up on each side of the wagon to be unpacked, facing inwards.

One trained non-commissioned officer should be told off to assist at every two wagons.

The flank men of each squad then get up into the wagon and hand down all the stores.

The numbers opposite the lashings unlash the pontoon. The pontoon will then be pushed off the wagon, the men taking hold of the handles in succession. The flank men will assist at the

* Field companies only.

bow and stern, and not at the handles. The pontoons must be carried by their handles, while a second relief should be beside them and hold on to their outer hands, leaning outwards. The men must be cautioned against damaging the pontoon by bumping it on the ground.

The words of command as given in the drill may be used if desired.

80. The method of unpacking a service trestle is only slightly different from that of a pontoon wagon. **Unpacking Service trestles.**

In unpacking, Nos. 2 and 7 mount the wagon, cast off the lashings, and hand down the tackles to Nos. 5, who carry them away. Nos. 6 assist to unlash and carry away shoes, grip and lever straps and brackets. The numbers then fall-in as for carrying away baulks (para. 73). Nos. 1, 2, 5, and 6 remove the legs and the baulks. Nos. 3 and 4 remove the ribands. A detachment then removes one trestle transom, while B detachment removes the other. The chesses are removed as when unpacking a pontoon wagon. In packing the process is reversed.

UNPACKING PONTOONS.

Detail of Duties of the Wagon Division in Unpacking Wagons.

Detachment.	Commander.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
A.	Puts on brake. Unbolts chess securers. Helps Bc to take off anchors. Lifts and launches pontoon. Carries away chesses. Sees chesses piled. Fastens up chess securers and sees wagon all correct and ground clear for next wagon.	Stands to wheel horses. Lifts and launches pontoon. Helps A 7 to carry away baulk or riband. Pushes out chesses. Carries away chesses. Helps A 7 to carry away anchor (112 lb.) and buoy when required	Gets up into pontoon. Unlashes superstructure. Assists B 2 to hand down stores and gets down. Lifts and launches pontoon. Helps A 6 to carry away baulk or riband Carries away chesses. Helps to carry away remaining stores, if any.	Receives breast-line and buoy and superstructure. Lifts and launches pontoon. Helps A 5 to carry away baulk or riband. Carries away chesses. Carries away two breastlines.	Unlashes pontoon and secures lashing. Lifts and launches pontoon. Helps B 4 to carry away baulk or riband. Carries away chesses. Helps to carry away remaining stores, if any.	Unlashes pontoon and secures lashing. Lifts and launches pontoon. Helps A 3 to carry away baulk or riband. Carries away chesses. Helps to carry away remaining stores, if any.	Receives breast-line and superstructure. Lifts and launches pontoon. Helps A 2 to carry away baulk or riband. Carries away chesses. Carries away anchor and buoy.	Gets up into pontoon. Unlashes superstructure. Hands down stores and gets down. Lifts and launches pontoon. Helps A 1 to carry away baulk or riband. Carries away chesses. Helps A 1 to carry away anchor (112 lb.) and buoy when required.
B.	Helps Ac to take off anchors. Lifts and launches pontoon. Carries away chesses. Sees chesses piled. Helps to carry away remaining stores, if any.	Stands to wheel horses. Lifts and launches pontoon. Helps B 7 to carry away baulk or riband. Pushes out chesses. Carries away chesses. Helps B 7 to carry away front cable.	Gets up into pontoon. Unlashes superstructure, assists A 2 to hand down stores and gets down. Lifts and launches pontoon. Helps B 6 to carry away baulk or riband. Carries away chesses. Helps to carry remaining stores, if any.	Receives cable (and buoy and buoy-line if 112 lb. anchor is used) and superstructure. Lifts and launches pontoon. Helps B 5 to carry away baulk or riband. Carries away chesses. Helps B 6 to carry away rear cable.	Unlashes pontoon and secures lashing. Lifts and launches pontoon. Helps A 4 to carry away baulk or riband. Carries away chesses. Helps to carry away remaining stores, if any.	Unlashes pontoon and secures lashing. Lifts and launches pontoon. Helps B 3 to carry away baulk or riband. Carries away chesses. Helps to carry away remaining stores, if any.	Receives cable superstructure. Lifts and launches pontoon. Helps B 2 to carry away baulk or riband. Carries away chesses. Helps B 3 to carry away rear cable.	Gets up into pontoon and assists A 7. Hands down stores and gets down. Lifts and launches pontoon. Helps B 1 to carry away baulk or riband. Carries away chesses. Helps B 1 to carry away front cable.

Packing Pontoons.

Detail of Duties of the Wagon Division in Packing Pontoons.

Detachment.	Commander.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
A.	Unbolts chess securers. Brings chesses. Directs and assists men in bringing up pontoon. Helps Bc to secure anchors. Fastens chess securers and sees wagon all correct.	Helps A 7 to bring 112 lb. anchor and buoy. Brings chesses. Helps A 7 to bring baulk or riband. Helps to bring pontoon. Stands to wheel horses.	Brings chesses. Helps A 6 to bring baulk or riband. Helps to bring pontoon. Mounts into pontoon and receives stores from A 3 and gets down.	Brings two breastlines. Brings chesses. Helps A 5 to bring baulk or riband. Helps to bring pontoon. Hands up breastline, buoy, and superstructure to A 2.	Brings chesses. Helps B 4 to bring baulk or riband. Helps to bring pontoon. Lashes pontoon to wagon.	Brings chesses. Helps A 3 to bring baulk or riband. Helps to bring pontoon. Lashes pontoon to wagon.	Brings anchor and buoy. Brings chesses. Helps A 2 to bring baulk or riband. Helps to bring pontoon. Hands up breastline and superstructure to A 7.	Helps A 1 to bring 112 lb. anchor and buoy. Brings chesses. Helps A 1 to bring baulk or riband. Helps to bring pontoon. Mounts into pontoon and receives stores from A 6 and gets down.
B.	Brings chesses. Fixes breastline to pontoon and assists to bring pontoon. Helps Ac to secure anchors.	Helps B 7 to bring front cable. Brings chesses. Helps B 7 to bring baulk or riband. Helps to bring pontoon. Stands to wheel horses.	Brings chesses. Helps B 6 to bring baulk or riband. Helps to bring pontoon. Mounts into pontoon and receives stores from B 3 and gets down.	Helps B 6 to bring rear cable. Brings chesses. Helps B 5 to bring baulk or riband. Helps to bring pontoon. Hands up cable (and buoy and buoyline, if 112 lb. anchor is used) and superstructure to B 2.	Brings chesses. Helps A 4 to bring baulk or riband. Helps to bring pontoon. Lashes pontoon to wagon.	Brings chesses. Helps B 3 to bring baulk or riband. Helps to bring pontoon. Lashes pontoon to wagon.	Helps B 3 to bring rear cable. Brings chesses. Helps B 2 to bring baulk or riband. Helps to bring pontoon. Hands up cable and superstructure to B 7.	Helps B 1 to bring front cable. Brings chesses. Helps B 1 to bring baulk or riband. Helps to bring pontoon. Mounts into pontoon and receives stores from B 6 and gets down.

Pontooning.

Forming up (a).

Forming up.

81. This drill is arranged for a bridge party of 6 N.C.Os. and 42 men and a spare Division, the strength of which will vary according to circumstances as previously mentioned (para. **66**), but is here given as for 6 N.C.O.s and 42 men only, which would be the numbers required for a large rapid river.

Detail.			N.C.Os.	Men.
No. 2 or Bridge Division	No. 3 Bridge Section	E Detachment	1	7
		F "	1	7
	No. 4 " "	G "	1	7
		H "	1	7
	No. 5 " "	I "	1	7
		J "	1	7
	No. 6 Spare "	K "	1	7
		L "	1	7

Forming up in quick time.

82. The party is formed up in column of Detachments at 4 paces interval, at the place where the bridge is to be made with the river on the left flank. Nos. 1 are furthest from and Commanders are nearest to the bank.

Officers or N.C.Os. are then told off as Commanders of every Section (two detachments) and are designated S.3., S.4., S.5., &c.

NUMBER YOUR SECTIONS FROM THE FRONT. Section Commanders number their Sections:—No. 3 Section, No. 4 Section, No. 5 Section successively.

Forming up.

LETTER YOUR DETACHMENTS FROM THE FRONT. Detachment Commanders take a pace to the front, turning towards their Detachments as they do so, and letter their Detachment "E" Detachment, "F" Detachment, &c., in rapid succession.

DETACHMENTS NUMBER. Whereupon Detachments number 1, 2, 3, 4, 5, 6, 7, Commander.

Duties of Section Commanders.

STAND EASY. The officer in charge will now detail the duties of the Section Commanders.

S.3.

S.3. will superintend the supply of superstructure for the bridge, and regulates the stream of traffic to prevent crossing, usually remaining for this purpose on shore at the tail of the bridge. He is responsible for marking the alignment of the bridge, and for the final

Forming up.

NOTES.

Before commencing the drill the officer in charge will give any special instructions as to cuts, centre of line of bridge, distance of anchors, and the direction in which the bows of the pontoons should point, &c.

Forming up.

picketing down of the shore end at the tail of the bridge, on the command "COMPLETE BRIDGE," and for supplying the extra chesses for cuts, using for these purposes any men of his section who may be most readily available.

S.4. S.4. is responsible for the construction of the bridge and for the final picketing down of the shore end at the head of the bridge at the command "COMPLETE BRIDGE," using any men of his section most readily available. His position is at the head of the bridge, he repeats the command "*Form bridge*" and he will give the command "*Out*" as each bay of baulks is placed on a fresh pontoon. He will inform S.3. when extra chesses are required for a cut.

S.5. S.5. is responsible for marking the alignment of the Up and Down stream anchors.

All Section Commanders are responsible for all work done by their Section, through the Detachment Commanders.

IN QUICK TIME FORM BRIDGE. E, G, I DETACHMENTS. ABOUT TURN. STAND EASY. TELL OFF DUTIES.

The Detachments named turn about, stand easy, and S.3., S.4., and S.5. tell off duties in a modulated tone of voice, moving between the ranks to do so if necessary. On completion S.3., S.4., S.5. give the commands "*No. 1 (2 or 3) section: attention.*" "*E (G or I) Detachments: about turn: stand easy.*"

The words of command for forming bridge in quick time are—

"IN QUICK TIME—FORM BRIDGE."

"*Form Bridge.*" Repeated by S.4.

"BAULKS."

"*Out*" by S.4.

"CHESSES."

The words "BAULKS, *Out*, CHESSES" will be repeated until the last bay of the bridge is laid, then

On the command, "COMPLETE BRIDGE," S.3. and S.4. arrange for the final picketing of the bridge shore ends at the tail and head respectively, and the whole party fall in as before on the shore and stand at ease.

S.3. Details of duties of E and F detachments.

On the command "BAULKS," E.1., 2, 3, 4, 5 take the front end, and F.1, 2, 3, 4, 5 the rear end of a baulk, Nos. 1, 2, 3 in the right hand, Nos. 4 and 5 in the left hand, No. 1 on the right. E.6. and 7 take the front end, F.6. and 7 the rear end of a riband in the outer hand, 6 on the right and carry them to the bridge at the same time as and behind the baulks, but always working two bays from the head of the bridge.

Forming up.

NOTES.

The words of command given by the officer in charge are printed in capitals; those by the section commanders in italics.

Baulks to be carried claws downwards. Baulk numbers will move slightly in echelon, to prevent crowding.

Chesses should be laid out at right angles to the bank of the river. F.C. should stand at the front end of the chess piles when these are on the right side of the bridge, and at the rear end when they are on the left. He will commence on the pile to his right, and will lift up that edge of the chess which is to his right.

Forming up.

The baulk numbers of E detachment place the front ends of the baulks in the proper cleats of the saddles of the pontoon. When they are all in position S.4. gives the command "*Out*," and the men push the pontoons out placing the shore ends of the baulks in the shore transom.

For the last two bays, two ribands must be brought up at the same time, one in each hand. Nos. 6 and 7 of each detachment also rack down the last bay. After placing baulks and ribands, each man will turn to his left and file off on the left side of the bridge. The whole will then be in order for bringing up chesses. On the command "CHESSES," F.7. and 6, E.7. and 6, F.5., 4, 3, 2, 1, E.5., 4, 3, 2, 1, and E.C. each bring up a chess in the right hand in the order named. F.C. remains at the chess pile tossing chesses to the chess numbers.

S.4. Details of duties of G and H detachments.

On the command "FORM BRIDGE," G.1., 2 bring up the shore transom, and then remain at the head of the bridge laying chesses received from the chess numbers, walking backwards on the baulks. G.2. on the right. As each pontoon arrives at the head of the bridge they will take charge of it. G.3., 4 always remain in the pontoon at the head of the bridge. G.4. on the right. They cast off, coil up, and replace the warping lines on the end of the saddle, push ends of baulks over to sides of cleats and chock, receive cables from anchor boats and temporarily belay them when baulks of new bay are in position. G.5., 6, bring up 3 inside and 2 outside shore baulks for the shore end and then take over cables from G.3., 4, belay, finally dressing bridge while doing so, coil up and stow them. G.6. works on the right. They then remain in their pontoon until G.3., 4 are ready to hand over the next pair of cables. G.C. brings up 1 chess and G.7. 2 chesses for the shore end and then rack down on the up-stream side of bridge.

H.C. carries a boathook, and is responsible for the supply of pontoons, and also for the supply of the head shore end together with four pickets and a maul. He will see that the saddles and couplings are properly fastened, cut baulks properly placed, and that each pontoon has its proper complement of oars, rack sticks and breastlines. He travels to the head of the bridge in each pontoon as it is warped up and hands them over to G.1. and 2. H.1. fastens a warping line to each pontoon and hands it to H.2., 3, 4, 5, who warp the pontoons to the head of the bridge, one at a time, behind the chess men. H.6. and 7 rack down on the down-stream side of the bridge, using spare rack lashings for the first bay.

S.5. I and J Detachments.

I and J Detachments form the boats' crews; Nos. 1, 2, 3, and 4 are the rowing numbers; Nos. 1 and 3 starboard, 2 and 4 port. No. 5 takes a lifebuoy on board and remains in the bow casting and weighing anchors, which he receives from Nos. 6 and 7 who are on the shore.

Forming up.

NOTES.

Chesses must be carried under the right arm, front end up, and outside the man in front, to prevent accidents.

Men carrying chesses or stores will go on to the bridge on the right and come off on the left. (Pl. XIV.).

Ribands must be placed with the rounded edges of ends downwards.

For medium bridge, baulks are placed in the inner high cleats of each half saddle and in the space over the junction of the half saddles. For the sake of uniformity chocks are placed in right side of baulks in cleats. G.3. and 4 must always have a cable in each pontoon at the head before S.3. gives the word "*Out.*" G.1. and 2 must hold each fresh pontoon brought up, while G.3. and 4 get into it. They must place the 15th chess on the 14th and remove the chocks so as to allow the next set of baulks to be inserted. As a rule a cable is required for every other pontoon, but there must always be one to boats next to "cut" rafts. G.7., G.C. rack down the up-stream side because the down-stream side is allotted to H detachment for easier supervision, as they must work on the down-stream side. Six spare rack lashings must always be used for the first bay; the rack lashings in each pontoon being used for the off shore bay. Half hitches must never be used in fastening cables to pontoons as they cannot be cast off quickly in case of need or accident.

Pontoons must always be warped up on the down-stream side of the bridge. The bow end should always be placed up-stream. Warping lines should be fastened to the second or third handle according to the strength of the stream, from the front on the inshore side.

The proper complement of stores for each pontoon is:—

5 oars,
6 rack sticks,
3 breast-lines,
1 boathook,
1 bailer.

The proportion of anchors, cables, and buoys to be stacked on shore depends upon the nature of the stream, usually it is one to each pontoon.

Cut rafts and pontoons adjoining cuts should be provided with extra cables and breast lines to facilitate making cuts and swinging if the bridge is long and the current strong.

Great care must be taken to cast anchors of "cut" rafts very

Forming up.

Nos. 6 and 7 keep the anchor boats supplied with anchors, cables, buoys, buoy lines, properly bent together and coiled; they also place the shore anchors at the tail of the bridge. The Commanders steer.

Manning bridge.

83. On the completion of the bridge the Detachments should fall in as before, in column on the shore. They are told off in succession to rafts of two or more boats at the discretion of the officer in charge, and filed on to the bridge, right in front; Commander and even numbers on the right, odd numbers on the left. Nos. 5 and 6 go at once to the cables, and the other numbers stand at attention facing the head of the bridge, and distributed along the raft.

If there are more than two cables on any raft, its Commander will tell off the necessary additional numbers for them, odd and even numbers always working on their own sides, the highest numbers being taken for the duty first.

TELL OFF RAFTS. The officer in charge should then give the command "TELL OFF RAFTS," on which the Commanders will in succession number off their rafts from the tail of the bridge.

DRESS BRIDGE. On the command "DRESS BRIDGE," the Commanders place themselves in the centre of their rafts, facing the officer who gives the command. Nos. 5 and 6 stand to their cables and cast off the belaying turns. The other numbers sit down on the bridge. The Commanders direct Nos. 5 and 6 to pay off or haul up, as required to bring them into covering with the points given to dress on.

Forming up in Double Time.

84. In forming bridge in double time the words of command are "IN DOUBLE TIME FORM BRIDGE," "*Out*" by S.4., and repeated by him for each bay.

Dismantling.

Dismantling in Quick Time.

85. In dismantling from forming up the wagon and bridge divisions fall in as for forming up.

The words of command are:—

"IN QUICK TIME DISMANTLE."

"CHESSES," "*Baulks*," by S.4., } being repeated until the bridge is dismantled.

As for forming up.

S.3. Detail of duties of E and F Detachments.

On the command "IN QUICK TIME DISMANTLE," E.6. and 7, F.6. and 7 unrack the shore bay at the head of the bridge, and carry away both ribands two at a time, throwing the rack lashings in the pontoon at the head of the bridge. They afterwards carry off two ribands at a time in front of each set of baulks.

Forming up.

NOTES.

exactly. In tidal waters heavy anchors are sometimes used on the up-stream, and light anchors on the down-stream side of the bridge, but "cut" rafts should if possible have a heavy anchor on the down as well as on the up stream side.

The theoretical distance of anchors from the bridge is ten times the depth of water, but this can rarely be attained, and 30 to 40 yards is about the normal distance. The greater the current and depth of water, the greater must this distance be. Anchors at the head and tail of the bridge should usually be placed on shore.

As a rule the anchor should be rather closer to the shore than the pontoon to which it is attached, in order that it may assist in keeping the shore end close to the shore, and also to check any tendency of the "cut" space to diminish when a "cut" is made.

Dismantling.

NOTES.

The duties of S.3., 4, and 5, and of all Detachments, are similar to those in forming up in the reverse order.

The duties of each will be detailed in the same manner as for forming up.

In dismantling the shore bay at the head of the bridge, the ends of the baulks on the shore transom are first cleared from the shore transom by H Detachment as detailed by H.C.

In dismantling the second and successive bays from the head of the bridge E.1., 2, 3, 4, and 5 lift up the ends of the baulks and draw them in, passing them through their hands till the pontoons touch, when with F.1., 2, 3, 4, 5 they take them away

Dismantling.

On the command "CHESSES," E.C., 1, 2, 3, 4, 5, F.1, 2, 3, 4, 5, E.6., 7, F.6., 7, take a chess in succession from G.1. and 2, and carry them away under their right arms on the left side of the bridge.

F.C. directs the chesses to be piled in four heaps to avoid crowding at the chess pile.

On the command "*Baulks*" by S.4., E.1., 2, 3, 4, 5 lift up the off shore ends of the baulks of the landing bay out of the cleats of the saddle and with F.1., 2, 3, 4, 5 carry them away.

S.4. Detail of duties of G and H Detachments.

G.3. and 4 always remain in the pontoon at the head of the bridge as in "Forming up." They fasten warping lines to the second handle from the bow of each pontoon in succession. They cast off cables, and assisted by G.1 and 2 pass them to the anchor boats, and remove chocks.

G.1. and 2 stand as in "Forming up" and toss up chesses in succession to E and F Detachments. They finally carry away the shore transom at the tail of the bridge.

G.C. and G.7. unrack on the up-stream side of the bridge, and will then report to S.3. as spare numbers.

G.5. and 6 are spare numbers, and will report as such to S.5.

H.C. and H.1. clear shore end and transom at the head of the bridge and bring them to shore in the first pontoon to leave the head of the bridge. H.C., H.2., 3, 4, 5 warp pontoons to shore. H.1. casts off warping lines and stores them. H.6. and 7 unrack on the down-stream side of the bridge. On completion of these duties they become spare numbers and report to S 3.

S.5. Detail of duties of I and J Detachments.

The boats' crews composed as in forming up, take the anchors, &c., ashore as they receive them, and hand them over to Nos. 6 and 7, who prepare them for packing.

Dismantling in double time.

86. In dismantling bridge in double time the words of command are:—

"IN DOUBLE TIME DISMANTLE."

"*Baulks*" by S.4. when the baulks of each bay are to be received.

Dismantling.

NOTES.

in the same manner as they brought them up, F Detachment leading.

S.4. must see that all the men are ready to lift before giving the command "*Baulks.*"

Spare detachments or men should be detailed to assist E and F Detachments in carrying chesses.

The shore end at the tail of the bridge is removed by men specially detailed by S.4.

Warping lines must be fastened to the second handle from the bow on that side of the pontoon which will be nearest the bridge when the pontoon is being warped away on the down-stream side of the bridge.

G.C. and G.7., H.6. and H.7., commence unracking at the second bay from the head of the bridge and stow the six rack lashings of each bay in the next pontoon nearest the tail of the bridge.

To prevent crowding, the numbers unracking and carrying away ribands should always be working at a distance of two bays from the head of the bridge.

The six rack lashings of the shore bay will be handed to S.3.

Forming Rafts.

Forming rafts, and bridge from rafts (b).

Forming bridge from rafts.

87. For forming bridge from rafts, the first operation to be performed is to make the rafts. For this purpose as many wagons as soon as possible are drawn up and unpacked in the ordinary way, except that all the pontoons are placed in the water before the superstructure is moved.

Forming rafts in quick time.

The following is the drill for forming rafts of two pontoons, and their superstructure. (Pl. XV.)

A Detachment of one non-commissioned officer and 7 men is normally required for each raft. The duties of each Detachment are similar.

The officer in charge will notify raft Commanders as to what superstructure each raft is to carry, and how the bows of the rafts should point, cut rafts, &c. (para. **97**).

Raft Detachments should be numbered off (from front or rear), No. 1 raft, No. 2 raft, &c.

As a rule No. 1 raft should be at the tail of the bridge.

Officers and serjeants should be told off to superintend two or more rafts, to mark off the alignments of the bridge and anchors.

While the raft is being constructed, the right and left pontoon are those on the right and left hand (facing the river) respectively.

When the raft is formed the Commander's pontoon is known as the right or starboard pontoon.

Detail of drill.

IN QUICK TIME, FORM RAFT.

In forming rafts in quick time the Commander and No. 7 get two pontoons, and hold them at right angles to the bank and 15 feet apart, bow ends towards the shore. Commander on the right.

BAULKS.

Nos. 1 and 2 bring one baulk, get into left and right pontoons, and walking on the inner gunnels and thwarts of each boat, and working together place the baulk in the off-shore cleats (Pl. XV., Fig. 1), and insert the chocks; over the right pontoon chocks are placed on the in-shore side and over the left pontoon on the off-shore side of the baulks.

Nos. 3 and 4 bring two baulks, and 5 and 6 also two baulks, two at a time (even numbers on the right), which are placed by 1 and 2 in succession, working from off shore inwards.

When the third baulk is placed, No. 7 gets a breastline and passes it through the rings at the bows of the two pontoons, and hands the ends to the commander.

The Commander of each raft must see that the baulks are properly placed against the sides of the cleats and the chocks inserted by

Detail of Duties of the Bridge Division in making a Bri

Detachment.	Section Commander.	Detachment Commander.	No. 1.	No. 2.	No. 3.	No. 4.
E	S3. Stands at tail of bridge and superintends supply of superstructure. Marks line of bridge, pickets down shore-end at tail, and superintends supply of extra chesses for cuts. Tells off duties of section.	Brings 15th chess.	Each man brings the front end of a baulk, the rear en is carried by the corresponding number of F Detachm man brings a chess.			
F		Lifts at chess pile.	Each man brings the rear end of a baulk, the front en is carried by the corresponding number of E Detachm man brings a chess.			
G	S4. Stands at head of bridge and is responsible for construction of bridge and picketing shore-end at head of bridge. Repeats command "Form Bridge" and also "Out" as each bay of baulks is placed. Informs S3 when extra chesses are required for cut. Tells off duties of section.	Brings up one chess and assists G 7 to place shore-end at tail of bridge. Racks down on up-stream side.	Bring up shore transom and lay it in position. Lay chesses, turning back the 15th chess and remove chocks. Left Side.	Right Side.	Gets into head pontoon with left cable and temporarily belays. Adjust ends of baulks in cleats of saddle and place chocks. Cast off, stow warping lines. Left Side.	Gets into head pontoon with right cable and temporarily belays. Right Side.
H		Responsible for supply of pontoons and stores for head shore-end. Sees that saddles and couplings are properly secured, cut baulks properly placed, and that each pontoon is properly equipped. Travels to head with each pontoon.	Secures warping lines to pontoon.	Warp up pontoons in succession to head o		
I	S5. Tells off duties of section. Marks alignment of up- and down-stream anchors.	Charge of right boat. Fixes steering oar and steers. Keeps G 4 supplied with cables.	No. 1 or bow oar.	No. 2 oar.	No. 3 oar.	No. 4 or stroke oar.
J		Charge of left boat. Fixes steering oar and steers. Keeps G 3 supplied with cables.	No. 1 or bow oar.	No. 2 oar.	No. 3 oar.	No. 4 or stroke oar.

Nos. 1 and 2, otherwise the cleats become blocked and the rafts cannot subsequently be joined together.

Nos. 1 and 2 then get into position for laying chesses, No. 2 off shore, and No. 1 in shore.

CHESSES.

Nos. 3, 4, 5, 6, and 7 bring six chesses each, and 1 and 2 double chess the raft. With the first four chesses brought up a gangway is formed, the first two being placed across the gunwales the next two from the shore to the bow end of the right pontoon. (Pl. XV., Fig. 2.) The chesses are then laid as in forming up, the first being placed with its outer edge over the centre of the saddle, because in the absence of button baulks there is a risk of subsequent bays of chesses not fitting in.

As soon as all are placed, the end pile of chesses on the right hand pontoon and the two end piles over the left pontoon are removed and distributed in a single layer over those next to them, so that over the right pontoon there are two piles of chesses three deep, and over the left pontoon four piles of chesses three deep. This is to allow room for No. 4 to row between the 2nd and 3rd baulks from the bows and for subsequent baulks to be placed on the saddles.

BAULKS AND RIBANDS.

Nos. 1 and 2 then fetch another baulk, and 3, 4, 5, and 6 bring the other four baulks and four ribands, two at a time; they are arranged by 1 and 2 across the chesses. No. 7 takes the boat-hook from his pontoon and gets on to the raft, which he holds in position (Pl. XV., Fig. 3), and the Commander casts off his breastline and fastens it to the up-stream thwart of whichever pontoon will be in shore in bridge.

STORES.

The Commander superintends and checks the stores brought up by the other numbers and gets ready for steering, 3 and 4 bring on board the anchors, buoys and buoy lines, Nos. 5 and 6 the cables. The up-stream anchors are placed towards the bow ends. Nos. 1, 2, 3 and 4 get into position for rowing. (Pl. XV., Fig. 3.) Nos. 5, 6, and 7 remain on deck and square up all stores, bend cables and prepare anchors for casting.

Nos. 1 and 2 sit on the belaying cleats in the bows, No. 4 on the outside portion of the second thwart from the bows of the left pontoon, using his oar under the superstructure, and No. 3 on the outer portion of the thwart nearest the stern of the right pontoon. (Pl XV., Fig. 3.)

When there is plenty of room, rafts may be rowed with the oars outside them, and managed as in an ordinary boat, but when coming into bridge the oars should be used between the pontoons. In this case the raft can only be steered by the steering oar.

Commanders must always have spare breast-lines ready for throwing, and if required spare cables for swinging bridge. Cut rafts must be provided with warping lines bent and coiled ready for use.

Commanders must see before leaving shore that each pontoon has its proper complement of rack sticks on board.

Rafts of more than two pontoons should be made in the manner described for the formation of portions of bridge for swinging (para. **92**).

Forming Rafts in Double Time.

88. In double time the work is the same, the word of command being:—

"IN DOUBLE TIME, FORM RAFT."

Forming Bridge from Rafts.

89. A sufficient number of rafts for the proposed bridge having been prepared, arrangements have to be made for moving them to the required spot to form bridge.

Before moving off, the rafts are numbered from right to left, and are usually told off in two Divisions, if this has not been previously done.

They are then rowed away in either single or double column. When long distances have to be covered, it will be found advisable to connect the rafts together, stern to stern, the rafts being disconnected on approaching the site of the bridge.

In forming bridge, if the rafts are in single column, the leading raft anchors and gets out the shore bay. The remaining rafts as they arrive form up in succession on the leading raft, all the bow ends up stream.

If the rafts are in double column, the two leading rafts anchor at opposite sides of the river and get out the shore and landing bays.

The remaining rafts of each column form up in succession to their leading raft, until the bridge meets in the middle of the river.

If the rafts are required to form a bridge independently of any other bridge equipment, a shore end complete, 4 pickets and 1 maul must be put on board the rafts which will be at the head and tail of the bridge. The latter must also be loaded with a complete shore bay and six extra rack lashings.

When cuts have to be made, each of the rafts which is next to a cut raft in bridge must be prepared with cut baulks (Pl. VII., Figs. 1 and 2), and must carry six chesses for the cut.

An example of the method of forming bridge from single column independently of the other bridge equipment is given below. The plan of anchoring described would apply to all cases to where boats were not available.

IN QUICK TIME, FORM BRIDGE.

90. On arrival at the spot where the bridge is to be formed, the Commander of the raft, to be at the tail of the bridge, casts his upper and lower anchors at the proper places, belaying his cables to the off-shore pontoon. It is generally best to send the two anchors on shore for casting, 5 and 6 work the anchors and cables throughout.

No. 6 on that side which in bridge will be the right.

Commander and No. 7 go ashore with the shore transom and 1, 2, 3, and 4 give them the ends of the baulks to place and pass them the shore end, pickets and maul.

The remaining rafts in succession, at 30 yards distance, cast their stream anchors a little way up stream and drop a similar distance down stream to cast their lower anchors, bending the ends of their cables together with a double sheet bend to enable them to do so. Those rafts which have to be formed up with bows down stream must now be turned round by hauling on the cables till they are in the correct position.

They then haul up opposite the place for the bridge, and look towards the tail of the bridge, and keep their raft in its proper position.

When the baulks connecting their raft to that in shore of them are placed, Nos. 5 and 6 belay and stow their cables in the off-shore pontoon.

Each Commander stows away his steering oar directly his lower anchor is cast, and all oars are shipped, and chocks removed by rowing numbers, who also unship their rowlocks.

The rowing number at the up-stream end of the in-shore pontoon of each raft casts a breast-line, previously fastened by him to the thwart of his in-shore pontoon, to the Commander of the raft in bridge, who hauls it in, and passes it to the rowing number at the up-stream end of *his* off-shore pontoon, who will take a turn round the corresponding thwart on his pontoon. If the wind is strong this may be done in the manner which best suits the wind.

(C) Baulks. Commanders and Nos. 1, 2, 3, and 4 of all Detachments place the baulks, working on the off-shore sides of their rafts. They pass the baulks to the Commander and No. 7 of the next raft from them, who place their ends in the cleats; they then push off until they can drop the ends of the baulks into the cleats of the saddle of their own pontoons, the Nos. 7 slacking their breastlines until the baulks are placed, when they make fast.

The ribands are then laid on the gunnels of the pontoon.

(C) Chesses. Nos. 1 and 2 of Detachments lay chesses, working backward towards the head of the bridge, 2 on the right and 1 on the left of the bridge.

Nos. 3, 4, 7 with 5 and 6 (who can now leave their cables), stand covering on No. 3 on the left side, facing the tail of the bridge, and bring three chesses each, commencing from the tail end of their own raft; the Commander lifts the ends of the chesses.

The commander gets the rack lashings out of the pontoons and distributes them in their places on the bridge.

(C) Ribands. Nos. 3, 4, 5 and 6, working on their own sides of the bridge, place the four ribands, those off shore first; and all hands rack down.

The landing bay is placed in the same way as the shore bay, and the bridge is completed.

As each raft and bay are completed, the crew stand up on the former, facing the head of the bridge, the Commander and even numbers on the right, the odd numbers on the left side of the bridge. They cover from the front and stand at ease.

DRESS BRIDGE. As before (para. **83**).

STEADY; BELAY. At these words Nos. 5 and 6 belay their cables and stow the coils in the pontoons. The other numbers stand up in their places.

In forming bridge from rafts in double time, the duties and commands are the same as for quick time.

In breaking up a bridge into rafts each raft's crew stands on its raft facing the head of the bridge, the Commander and even numbers on the right, the odd numbers on the left, covering from the front.

Breaking up a bridge into rafts.

IN QUICK TIME, BREAK INTO RAFTS; UNRACK. 91. Each raft and bay is unracked by the whole of its crew. The Commander collects and stows the rack lashings. The crew of the raft at the tail of the bridge have also to unrack the shore bay. Breaking into rafts in quick time.

(*C*) *Ribands.* Nos. 3, 4, 5 and 6, place the four ribands of the raft and bay across the gunnels of the two pontoons of their raft, the even numbers working on the right, and the odd numbers on the left side of the bridge. The ribands of the shore bay are in a similar way brought on to the raft at the tail of the bridge.

(*C*) *Chesses.* Nos. 1 and 2 stand respectively on the left and right sides of the bridge at the extreme end of their bay, facing towards their raft.

Nos. 3, 4, 5, 6, and 7, stand covering on No. 7 on the right side of the bridge, facing 1 and 2.

Nos. 1 and 2 toss up the chesses in succession to 3, 4, 5, 6 and 7, who double chess their raft, the Commander assisting to lay the chesses, commencing at their in-shore end, turning up the end chesses as directed in " Forming rafts," so that when finished each raft has two layers of twelve chesses, and two additional chesses in a third layer at the end over the port pontoon, and four at the end over the starboard pontoon. The raft at the tail of the bridge is treble chessed in a similar manner with the chesses of the shore bay.

LANDING AND SHORE BAYS. Commander and No. 7 of the rafts at the head and tail of the bridge go ashore, pass the shore baulks on to their rafts, lift the ends of the baulks of the landing and shore bays out of the transoms, and return on board with the transoms. Nos. 1, 2, 3 and 4 haul these baulks on board and arrange them across the chesses.

(*C*) *Baulks.* Nos. 5 and 6 get into the wells of the pontoons and make ready to cast off cables. Nos. 1, 2, 3, and 4 of each raft working together on the off-shore side, and Commander and No. 7 of the next raft working on the in-shore side, remove all the baulks, first lifting the three centre baulks, then the two outer baulks, (these latter must be moved together), and arrange them across the chesses. They then place the four ribands alongside the baulks and get into position for rowing with oars tossed.

(C) *Bend cables.* Nos. 5 and 6 of each raft pass up the coils of their cables on to the deck, cast off the turns round the belaying cleats, and come up on deck, keeping a strain on their cables. Commanders and No. 7 bend the ends of the cables together with a double sheet bend.

(C) *Cast loose.* The rowing number at the up-stream end of the off-shore pontoon casts loose the breastline, fastening his raft to the next raft on the off-shore side, whose rowing number at the up-stream end of the in-shore pontoon hauls it in and stows it.

WEIGH LOWER ANCHORS. Nos. 5 or 6, assisted by No. 7, hauls down to the anchor and weighs it. The Commander gets into position for steering, gets out his oar, and gives the word "*Down*" to the rowing numbers.

(C) *Weigh stream anchor.* No. 6 or 5, assisted by No. 7, hauls up to the anchor and weighs it.

Nos. 5 and 6, as soon as their anchors are weighed, coil down their cables and buoy lines and make ready for recasting their anchors.

The rafts can now be rowed away in whatever direction required.

Breaking into rafts in double time. Breaking up a bridge into rafts in double time is performed in precisely the same way and with the same words of command.

Forming bridge for swinging and swinging bridge. (c).

Forming bridge for swinging. **92.** For forming bridge for swinging, as many wagons as possible are drawn up. The wagons are unpacked in the usual way except that all the pontoons are placed in the water before the superstructure is removed.

The circumstances under which bridges may be swung vary, so that every case requires special consideration.

The bridge is made in a series of rafts which are joined up at the place where the bridge is constructed. A detachment of one non-commissioned officer and seven men is required for each raft (para. **87**).

The drill in the following pages is given for a portion of a bridge of six pontoons, made by three detachments. The raft at the head of the bridge, Nos. 1 and 2 pontoons (Pl. XVII.) is made in the same way as in forming bridge from rafts, as the bay at the head of the bridge must be double-chessed.

Pl. XVII. shows portions of the bridge in different stages of completion, the head of the bridge being to the left (up-stream).

IN QUICK TIME, FORM BRIDGE FOR SWINGING. The Commanders and Nos. 7 get two pontoons, and each holds one pontoon at right angles to the bank, 15 feet apart, bow ends toward the shore

If a three-boat raft be required in the bridge, a spare man must be told off to hold the third pontoon in position.

BAULKS. The first five baulks of each raft are brought up and placed as in forming rafts (para. **87**). Nos. 1 and 2 then bring up another baulk, which they place in the off-shore cleats connecting their own raft with that on their left or right as directed. Nos. 3 and 4, 5 and 6, bring the remaining four baulks, which are placed by 1 and 2.

CHESSES. Nos. 3, 4, 5, 6, 7 bring six chesses each, which are laid by 1 and 2 in the same manner as in making rafts, except that one continuous layer of chesses over raft and bay is laid.

Commanders take the rack lashings out of the pontoons and distribute them on the bridge. Nos. 7 take the boat hooks from their pontoons and get upon the bridge, which they hold in position.

RIBANDS. Nos. 3, 4, 5, 6 bring four ribands, which are received by 1 and 2, who, assisted by the commander, rack them down, in-shore ribands first.

STORES. Nos. 3, 4, 5, 6, then take the anchors and cables on to the bridge, together with any special stores which may have been detailed in the preliminary instruction (para. **87**).

When all is complete the men stand up on their raft facing the head of the bridge (that is, up-stream), even numbers (commander, 2, 4, 6) on the right and odd numbers on the left, and stand at ease. The raft at the head of the bridge must be double-chessed and provided with the necessary stores for the landing bay, which are arranged as those for the landing bay in forming bridge from rafts (para. **89**). If the bridge is to be swung where it is formed, the raft's crew at the tail of the bridge will place at the site of the bridge the superstructure and stores for the shore bay and shore end. If the bridge is to be swung at a different place from that where it is constructed, it will be necessary to place these stores and superstructure on the raft, double-chessing it as for the raft at the tail of the bridge. The position of the tail of the bridge before swinging should be slightly above the point at which the bridge is to be made.

PREPARE TO SWING BRIDGE TO THE RIGHT (*or* LEFT).

Swinging bridge to right (or left).

93. Nos. 5 and 6 of the two rafts at the tail of the bridge carry out their stream and lower anchors on shore, and cast them as usual, those for the raft at the tail of the bridge being kept on shore, and those for the other raft carried a little way into the water, so as to keep the cables leading to the bridge clear; 5 and 6 then return on to the bridge. Commanders and Nos. 7 bend cables.

No. 5 (or 6) of every raft, except the above two, takes up an anchor and holds it ready to cast on the stream side. All hands, commander excepted, stand by to pay off the stream cables as the anchors are cast.

SWING BRIDGE. The head of the bridge is pushed off from the shore, and being caught by the current, swings round. Each commander of a raft, as he comes in line with the guiding banneroles on shore (para. **16**), gives the word "*Cast anchor*," when 5 (or 6) casts the anchor. (The anchors of the five or six rafts which are nearest the tail of the bridge, exclusive of the two whose anchors are cast from the shore, should be carried about a distance of two bays towards the head of the bridge before being cast, and their cables then brought back to their proper rafts.) The whole of the numbers then stand by to pay out the cable, under the careful supervision of the commander, who regulates the pace so as to keep the bridge in dressing.

Cast anchor.

STEADY. Nos. 5 (or 6) hold their cables taut.

CAST LOWER ANCHORS. The shore end is pushed clear of the bank and the whole bridge is allowed to drop down until it is in line with the lower banneroles. The lower anchors are cast and the bridge hauled up into position by means of the cables. The operation is facilitated by detailing a party of men to work the shore end from the bank. When the stream is strong the lower anchors must be cast from boats detailed for the purpose.

STEADY. As before.

BELAY. Cables are unbent and Nos. 5 (or 6) belay their cables and stow them.

LANDING AND SHORE BAYS. The landing and shore bays are placed as in forming bridge from rafts (para. **90**).

Swinging bridge in double time.

94. In forming a bridge for swinging, and swinging it, in double time, the work done is the same, the words of command being:—

"IN DOUBLE TIME, FORM BRIDGE FOR SWINGING"; "PREPARE TO SWING BRIDGE TO THE RIGHT (*or* LEFT)"; "SWING BRIDGE"; "STEADY"; "CAST LOWER ANCHORS"; "STEADY"; "BELAY."

95. Swinging back a bridge with the stream, the operation is the reverse of that described above.

IN QUICK TIME, PREPARE TO SWING BRIDGE TO THE RIGHT (*or* LEFT). In swinging to the right or left the landing and shore bays are removed as usual. Nos. 5 and 6 bring the cables on deck, bend them together and hold on.*

WEIGH LOWER ANCHORS. The bridge is allowed to drop down stream and the lower anchors are weighed. In a strong stream this must be done from boats.

WEIGH STREAM ANCHORS. The bridge is hauled up by the cables and stream anchors are weighed. The bridge must be kept in dressing so that all the anchors may be weighed simultaneously.

SWING BRIDGE. The tail of the bridge is then pulled in at the proper place by means of the anchors on shore, and the current swings the bridge in. If the current is weak one of the shore cables may be taken to the head of the bridge and used as a warping line. Nos. 7 get their boathooks and stand by to fend off.

UNRACK. All hands unrack, the commanders collecting and stowing the rack lashings. Any anchors on board are taken ashore by Nos. 5 and 6.

RIBANDS, CHESSES, BAULKS. Each number undoes what he did in forming bridge, taking the stores ashore as they are named, and falling in when his work is completed.

Swinging back bridge in double time.

96. In swinging back a bridge in double time the work is the same, the words of command being:—

"PREPARE TO SWING BRIDGE TO THE RIGHT (*or* LEFT)"; "SWING BRIDGE"; "UNRACK."

Forming cuts.

Forming cuts.

97. Cuts (para. **12**) in bridges of the pontoon equipment are easily made, but as it is found difficult to re-form with full-length baulks, a special arrangement is provided.

In order to form a cut one or more rafts have to be disconnected at some pontoon selected for the purpose in the length of the bridge. These rafts should be designated beforehand, and the pontoons next to them provided with four special baulks. (Pl. VII., Figs. 1 and 2.) These baulks go into the intermediate cleats of the saddles when five baulks only are used in the bridge; if nine are used they are placed outside the cleats; they are not 6 inches deep, and can, after the chesses which rest on them have

* A bridge can always be controlled when swinging by passing the cable up or down the deck as required. In swinging portions of a bridge to let traffic pass, either one or more additional cables should be placed on the rafts at the head of the portion of the bridge that is swung; they should be bent on to the cables of those rafts before the bridge is swung.

been removed, slide in freely under the superstructure of a bay as far as their inner cleats. In order to make them slide in together they are connected by a pair of special light saddles so as to form a kind of frame. (Pl. VII., Fig. 2.)

This frame should be laid on the saddle-beam of the pontoon, which is to be the one next to the cut in the bridge, before the ordinary baulks and chesses are put down. This pontoon must be so placed in the bridge that the claws of the cut baulks are towards the cut.

If it is desired to add the cut baulks after a bay has been chessed, it is only necessary to remove three or four chesses, insert the cut baulks in their places, and attach them to their special saddles.

The pontoons on which the cut bay rests should be kept at a clear interval of about 6 inches by breast-lines and fenders. The breast-line should be permanently belayed to the thwarts of the bridge pontoon, and temporarily belayed to the thwarts of the cut raft, so that the loose end of the line is in the pontoon in bridge, and a short end only passed to the cut raft pontoon. Breast-lines for warping must also be made fast to the belaying cleats of the outer pontoons at the stream ends, and coiled down in these pontoons.

Duties in forming cuts.

98. The positions and duties of the men in forming a cut by removing a single raft of three pontoons are as follows:—

The detachments for the raft to be removed and for the bay on either side of the cut will be proved.

IN QUICK TIME, PREPARE TO FORM CUT IN BRIDGE.

At this command no one moves except the numbers on the "cut" raft. Nos. 5 and 6 pass up the coils of their cables on deck, cast off their belaying turns, and come on deck, keeping a strain on their cables; C and 7 bend together the up and down stream cables. Nos. 1, 2, 3, 4 take up positions in the ends of the outer pontoons. (Pl. XVIII., Fig. 1.)

Unrack.

Nos. 5 and 6 of the crews of the rafts in bridge next to the cut raft get into the ends of the pontoons nearest the cuts. Nos. 1, 2, 3, 4 of the same rafts double out on the cut bays and unrack them, sliding the extemporized short ribands well back on to the bridge on either side. C and No. 7 of the cut raft make fast warping lines to the belaying cleats of the outer pontoons at the stream end and bring them on to the deck.

Chesses.

Nos. 1, 2, 3, 4 unchess the cut bays, Nos. 1 and 2 lift chesses, and Nos. 3 and 4 step backwards and carry and place them in a pile on the bridge. The numbers in the pontoons pull out the end chesses, and place them on the ends of the ribands. C and No. 7 of the cut raft pass the ends of the warping lines to the corresponding numbers of the raft's crew on bridge. They are passed to that side of the bridge behind which the cut raft is to be placed when the cut is made, and are manned by the odd and even numbers respectively, the numbers on the down-stream side of the bridge, holding the in-shore warping line. (Pl. XIX.)

Lift and heave. The numbers in the pontoons of the cut raft seize the handles of the special saddles, and lift the cut baulks out of the pontoon saddles until the claws are just clear of the saddles, when they push the sets of baulks (assisted by Nos. 5 and 6 of the bridge rafts) in under the superstructure of the bridge as far as they will slide.

In doing this the numbers must take special care that they lift and heave together; if this is done the cut baulks will slide freely under the bridge.

Cast off breast-lines. The breast-lines which have been temporarily belayed to the thwarts of the cut raft pontoons are cast off by the numbers in the ends of these pontoons.

FORM CUT. The down-stream cables are hauled on, and the up-stream cables are paid out under the direction of the cut raft commander until the cut raft is well down below the bridge. On no account must it at this time be checked by the warping lines.

Check. As soon as it is well down, the commander of the cut raft holds up his right hand and shouts "*Check*"; the numbers holding the warping lines nearest the head of the bridge then haul sharply, so as to turn the pontoons of the cut raft about 45 degrees towards the standing part of the bridge behind which the cut raft has to be moved; the cut raft is thus made to swing quickly clear of the opening.

The raft is then warped up below the bridge by both warping lines so that the outer cut raft pontoon is behind the second pontoon from the cut.

C and No. 7 of the raft in bridge make fast the warping lines.

IN QUICK TIME, PREPARE TO RE-FORM BRIDGE. On this caution, C and No. 7 on the bridge cast loose the warping lines, and hold on to them.

RE-FORM BRIDGE. C and No. 7 come on to the deck paying out the warping lines and being careful not to check the cut raft, which is hauled down below the bridge by its down-stream cable, and then hauled up by its up-stream cable. The warping lines are kept on the bridge during the operation, so that cut can be formed again, if necessary, at any moment before bridge has been reformed.

Make fast breast-lines. The breast-lines will be taken and secured by Nos. 1, 2, 3, 4, of the cut raft to the thwarts.

C and No. 7 on the bridge pass back warping lines to the corresponding numbers on the cut raft, who coil them down in the pontoon.

Lift and heave. The sets of cut baulks are lifted by the Nos. 5 and 6 of the detachments of the bridge rafts, and adjusted on the saddles; one by Nos. 1 and 2, the other by Nos. 3 and 4 of the cut raft.

Chesses. The numbers in the pontoons replace the end chesses; the cut bays are chessed over by Nos. 1, 2, 3, 4, of the rafts in bridge next to the cut rafts.

Rack down. Nos. 1, 2, 3, 4, rack down.

The cables of the cut raft are then belayed, unbent, coiled and stowed away, and the bridge is complete.

Forming cut in double time. **99.** In double time the only commands are:—"IN DOUBLE TIME, FORM CUT," "IN DOUBLE TIME, RE-FORM BRIDGE."

Double cut. **100.** In making a double cut the duties are nearly the same, a raft's crew being on each side of the cut rafts.

Four extra men should be told off to unrack and unchess the interval between the two cut rafts; their place is on the cut raft which carries the cut baulks, where they will place the ribands and chesses.

Stores for cuts. **101.** The special stores required for making a single cut are:—

8 cut baulks.
4 short ribands (extemporized).
4 cut baulk saddles.
8 breast-lines for warping lines.

The stores for a double cut are:—

12 cut baulks.
6 short ribands (extemporized).
6 cut baulk saddles.
12 breast-lines.

Enlarging cut by swinging. **102.** It may often be desirable to enlarge the opening formed by a cut in the bridge by swinging either or both portions of the bridge. If sailing vessels are beating up against the wind, it is best to swing the two portions of the bridge in opposite directions. If this is likely to be required, the landing and shore transoms must not be picketed down or a cut should be made near the shore end.

PREPARE TO SWING BRIDGE TO THE RIGHT (*or* LEFT).	Nos. 5 and 6 of each raft jump into the ends of their pontoons, pass up the coils of their cables on deck, keeping a strain on their cables. Commanders and Nos. 7 bend the ends of the cables together. The crew of the raft at the tail of the bridge go ashore and move the shore transom round as the bridge swings. It is advisable to have breast-lines attached to the handles of the shore transoms, for hauling back again, should either handle be in the water.
SWING BRIDGE.	Nos. 5 (or 6), assisted by Nos. 1 and 3 (or 2 and 4), haul on their cables; Nos. 6 (or 5) slacking off until the word "Steady" is given; commanders look to the tail of the bridge, and regulate the hauling on the cables so as to keep the bridge in line.
STEADY.	All the numbers manning the cables hold on.
BELAY.	As usual.

The bridge is swung back in the same manner.

As the distance which a bridge can be swung depends on the position of the anchors and the length of the cables, it is necessary, in the case when a long bridge is required to be swung a considerable distance, to have on some of the rafts furthest from the shore, spare cables, to which the ends of the ordinary cables are bent.

Instead of this, when swinging with the stream it may be practicable to weigh the down-stream anchors, if they are so placed that in swinging the bridge comes over them; but this must be done very smartly, for if the bridge passes over them, it may be impossible to weigh them without swinging the bridge back.

Pontooning with weak detachments and untrained men.

103. If there are not sufficient men available to form complete detachments, the numbers laid down in the preceding drill must be modified on the following lines. The duties of E.C. and F.C. may be combined. Two men can carry down two baulks at a time, one in either hand. The racking-down numbers may be dispensed with, all hands being detailed for this after completion of the bridge. H detachment may be reduced to four numbers. I and J detachments may be reduced to the boat's crew only (five men). Modification with weak detachments.

Modification with untrained men.

104. Pontooning may be carried out by infantry and other untrained men, provided there is a fair percentage of trained men available to supervise and assist.

The following procedure or some modification of it to meet the circumstances may be adopted :—

Forming up.

The men are told off in exactly the same way as before, and their duties are the same. Trained officers, non-commissioned officers and men of the R.E. should be detailed for the most important duties, viz :—

Commanders of Sections (S.3., S.4., S.5.).

Commanders of Detachments (E.C., F.C., G.C., H.C., I.C., J.C.).

G.1., G.2., G.3., G.4., G.5.

I.1. and 6, J.1. and 6.

H.C. and H.1.

The above are in order of importance.

This will ensure the detachments being under proper control, and each detachment will do its own work, though the various numbers need not necessarily do the duties prescribed in the drill.

Forming rafts.

The Commanders and numbers 5, 6 and 7 should be trained men, and, if possible, 1 and 2 also.

Forming bridge from rafts.

As for forming rafts.

Swinging bridge.

If this operation is to be carried out with untrained men every opportunity must be taken to practise it before it is necessary to carry it out, but if the Commander, and Nos. 5, 6 and 7 are trained there should be little difficulty in obtaining efficiency rapidly.

Forming cuts.

This operation must be practised frequently after completion of the bridge. The trained numbers should be those laid down for making rafts.

Forming light bridge.

Forming Light bridge.

105. In making light bridge from the pontoons the bow and stern pieces are used as separate boats, having a saddle-beam in each piece.

The riband are used as baulks. The roadway is carried by three baulks, or two baulks and one riband, for each bay, the riband, when used, being placed between two baulks.

The following drill is arranged for a bridge division of six detachments told off as for "Forming up" (para. **81**).

The bridge is constructed by "Forming-up."

IN QUICK TIME—FORM LIGHT BRIDGE.

G.1. and G.2. place the shore-transom.

H detachment uncouple the pontoon sections and fix the saddles for light bridge. When the bows are all upstream, the saddle-beam of the bow-piece should be so placed that it has a bearing of about two inches on the sternmost gunwale. The saddle-beam of the stern piece should be so placed that it is clear of the gunwale of the pontoon, the end of the saddle being about one inch from the inner edge of the gunwale.

Button-baulks cannot be used for this bridge.

There will be one spare riband in every two bays of the bridge, so that for racking down, ribands can be used for every fourth bay, and oars for the intermediate bays.

An eighth chess will be required for every third bay.

I.6. and I.7., J.6. and J.7. place the shore anchors and take the ends of the cables to G.1. and G.2., who get into the first section, which is warped up by H.C. and H.1., and steady it in its place, close to the shore, by means of the cables, G.2. on the right, G.1. on the left.

The duties of G, H, I, and J detachments are the same as in "Forming-up" medium bridge.

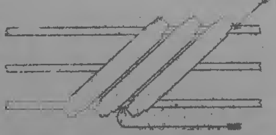
BAULKS. E detachment will bring up the baulks and ribands, moving slightly in echelon, under the supervision of E.C., whose duties are similar to those of S.4. in "Forming-up" medium bridge.

CHESSES. G.1. and G.2. stand on the baulks facing the shore, G.2. on the right, G.1. on the left.

F detachment carry on the chesses, under the supervision of F.C., on the right of the bridge.

G.1. and G.2. lay the chesses diagonally, as shown in the diagram below, the inside corner of the chess to be directly over the inner edge of the outside baulk. The first chess to be laid with its corner over the shore-transom, the second on the shore side of the first, the remainder off-shore, G.1. and G.2. working backwards.

Diagram for laying chesses.



Corners to which arrow heads point to be over centre of baulk, or over centre of saddle at commencement of each bay.

Forming light bridge in double time. **106.** In forming light bridge in double time the words of command are :—

"IN DOUBLE TIME—FORM LIGHT BRIDGE."
"BAULKS" and
"CHESSES"

being repeated.

In racking down, the numbers will always work two bays from the head of the bridge, obtaining their rack lashings from the pontoon sections.

When completing bridge the shore-transoms at the head and tail of the bridge will be picketed down by H detachment, under the supervision of H commander.

Heavy bridge.

General instructions. **107.** The heavy bridge is designed to carry motor lorries weighing $7\frac{1}{2}$ tons when loaded, having then 5 tons on the rear axle and a wheel base of 7 feet 6 inches. The width of wheel track varies from 5 feet $2\frac{1}{2}$ inches to 7 feet. The maximum turning radius of these vehicles is 48 feet.

The bridge may be used in streams with a current up to four miles an hour, and takes about twice the time required to make a medium bridge of the same length.

108. Each pier consists of one complete pontoon, *i.e.*, two sections joined together. The pontoons are placed 7 feet 6 inches apart from centre to centre. Trestles, when used, will be placed at 7′ 6″ intervals. (Pl. XI.)

Roadway. **109.** The roadway is carried on 14 baulks arranged as follows :—

Baulks.

(1) A group of six plain baulks under each wheel-track.
(2) One button-baulk outside each group.

Each of the groups of baulks in (1) will be arranged in two sets of three, separated by the third pair of cleats reckoned from the centre of the saddle-beam.

The outside baulks of each group will be placed 3 feet 6 inches from the centre of the saddle-beams. The inside baulks of each group will be ribands.

The baulks in (2) should be button-baulks, as these render the roadway more secure against shifting under a load.

If button-baulks are not available, plain baulks must be used. These baulks will be placed so as to come under the ends of the chesses, as described for medium bridge. (Pls. X. and XI.)

The baulks will be so placed as to break joint in consecutive bays. This will necessitate the use of seven half-baulks on each end of the floating portion of the bridge. Each Bridging Train carries 14 half-baulks for this purpose. (Pls. XI. and XII., Fig. 3.)

If the floating portion of the bridge consists of an odd number of bays, two half-button-baulks and two half-ribands for wheel-guides will be required in addition.

The roadway is double chessed, and the chesses are laced down to the baulks with $1\frac{1}{2}$-inch lashings. Chessing.

Ribands are placed as wheel-guides 3 feet 9 inches from the centre of the bridge, thus giving a roadway of 7 feet 6 inches in the clear. Wheel-guides.

They are held in position by three drop-bolts each, which are dropped through holes bored through the ribands and chesses. These bolts are $\frac{3}{4}$-inch in diameter, 13 inches long, with $1\frac{1}{2}$-inch cheese heads. Each pontoon and trestle wagon of the bridging train carries three such bolts. Drop-bolts.

At each shore-end the wheel-guides should be slightly splayed until they form a roadway 10 feet on the shore, so as to enable vehicles to get on to the bridge more easily. Shore-end.

The equipment of the Bridging Train is sufficient to make 125 yards of this bridge.

Local conditions may necessitate the provision of longitudinal bracing, extra footings, etc.

110. The following is the detail of the drill for the construction of *Heavy Bridge* by *Forming up* (Pls. X., XI. and XII.) :—

Forming up in quick time.

LETTER YOUR DETACHMENTS FROM THE FRONT. — As for medium bridge.

ARRANGE AND NUMBER YOUR DETACHMENTS. — As for medium bridge.

IN QUICK TIME FORM HEAVY BRIDGE. — At the command "FORM HEAVY BRIDGE" G.1. and G.2 bring up the shore transom, and with the assistance of the remainder of G detachment fix it in position.

H.C. and his detachment receive the pontoons from the unpacking divisions and H.C. will mark, with chalk, the cleats of the saddle-beams in which the baulks are to be placed. H.C. directs two pontoons to be brought up. H.2. and H.3. will secure the saddle-beams to the belaying cleats on the central partition of the pontoon by means of a one-inch lashing passed through No. 1 cleat, and the hinged straps on the bow and stern thwarts. H.1. attaches the warping lines to the second handle from the front of all successive pontoons. They are warped into position by the remaining numbers of H detachment.

I.6., I.7., J.6., J.7. place the shore anchors and bring the ends of the cables to the second

Notes.

In making a heavy bridge the bridging party will consist of the same numbers and will be organized into the same detachments as has already been described for Medium Bridge. The duties of the detachments will be generally the same.

The slowest part of the work is placing the baulks, and this must be done carefully, and cannot be hurried. Heavy bridges will not be made in double time for this reason.

Heavy bridge must be made either by *Forming up* or *Swinging*, but in the latter case the bridge must be constructed from one end only.

Cuts cannot be formed; if required, the necessary length of bridge must be dismantled.

In order to avoid confusion, all detail and executive words of command will be given by the officer in charge of the bridge.

The sections are formed up in column of detachments, lettered and numbered, and officers or non-commissioned officers detailed for the duties of S.3., S.4., S.5., or Commanders of Nos. 3, 4, or 5 Bridge Section, as for Medium Bridge.

S.4. takes post at the head of the bridge and superintends the placing of the baulks in their proper cleats.

S.3. takes post at the tail of the bridge, near to the superstructure, and, assisted by F.C., sees that the proper material is brought up by the numbers detailed.

S.5. superintends the work of the anchor boats and is responsible that the saddle-beams of the pontoons are correctly placed, lashed, and marked before being brought to the head of the bridge. He will see that the joint of the saddle-beam is directly over the joint between the two sections of the pontoon.

The fixing of the shore transom may sometimes mean a considerable amount of work, because the roadway of the bridge must be at such a level that the steam road transport can be driven on to it safely. The two pontoons for the first two bays are then placed in position and the half-baulks and baulks from the shore transom outwards are laid.

If a trestle is placed between the bank and the first pontoon the trestle must be regarded as the shore transom for purposes of the drill, and the subsequent arrangement of superstructure. Any superstructure shorewards of this trestle, which projects beyond the real shore transom, must be bedded in the ground.

pontoon. The remainder of I and J detachments form the crews of the anchor boats. In each case the commander takes the steering oar. 1 and 3 pull the starboard oars and 2 and 4 the port oars. No. 5 takes a lifebuoy into the boat with him, and his duties are to receive anchors from 6 and 7 and cast and weigh them as required, assisted, when necessary, by No. 1.

G.C. and G.7. get into the outer (or No. 2) pontoon, G.5. and G.6. get into the inner (or No. 1) pontoon. They hold the pontoons together. G.C. and G.7. receive the cables of the shore anchors from the numbers of I and J detachments and temporarily belay.

1st bay. HALF-BAULKS. G.1. and G.2. get into No. 1 pontoon with G.5. and G.6. G.3. and G.4. get into No. 2 pontoon with G.C. and G.7. (Pl. XII., Fig. 1.) These numbers of G detachment place themselves in their respective pontoons as follows :—

- G.C. and G.6. on the right, in the well of the pontoon, immediately outside the button-baulks.
- G.7. and G.5. on the left, in the well, immediately outside the button-baulks.
- G.3. in the well of the pontoon, on the left of the centre of the saddle-beam.
- G.4. in the well of the pontoon, on the right of the centre of the saddle-beam.
- G.1. and G.2. stand partly on the saddle-beam and partly on the central partition of the pontoon, G.2. on the right, G.1. on the left.

E detachment bring up seven half-baulks, and, under the direction of S.3., place and chock their shore ends, G.1., G.2., G.5., G.6. receiving the front ends of these half-baulks and placing them in their proper cleats, steadying them there until the shore ends are in position and chocked. G.5. and G.6. are responsible for keeping the pontoon at the proper distance from the shore transom. In order to avoid crowding, E detachment work in two ranks : Nos. 7, 5, 3, and 1 forming the front rank, Nos. 6, 4, and 2, the rear rank.

2nd bay. BAULKS. F.1., F.7., E.1., and E.7., bring up two button-baulks, F.2., F.3., F.5., F.6., E.2., E.3., E.5., and E.6. bring up four plain baulks, F.4. and E.4. bring up one riband.

NOTES.

F.2., F.3., F.5., F.6., E.2., E.3., E.5., E.6. always bring up plain baulks. F.4. and E.4. always bring up a riband.

Whenever F detachment lead after the word "BAULKS," F.1., F.7., E.1., and E.7. bring up button-baulks.

The numbers of F detachment lead, and corresponding numbers of the detachments work together.

S.4. places himself where he can best superintend the work.

The outer ends of these baulks and ribands are received by G.C. and G.7., G.3. and G.4. who place them in their proper cleats and chock them; G.1., G.2., G.5. and G.6. assisting to guide the centres of the baulks into their proper cleats of No. 1 saddle-beam. When the outer ends of the first four baulks are chocked, the numbers of F detachment push out as necessary, and place the shore ends of the baulks, S.4. being responsible that the proper cleats are used. The rear rank baulks are then passed out and placed in their proper positions.

CHESSES. G.1. and G.2. get up on to the baulks and prepare to lay chesses.

F.C. places himself at the chess pile and issues chesses.

F.1., 2, 3, 4, 5, 6, 7, E.1., 2, 3, 4, 5, 6, 7, and E.C. each bring up one chess. The chesses are laid double. The last chess is turned back over the last pair of chesses.

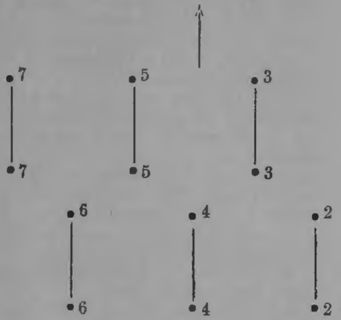
H.C. provides himself with a boathook and directs the third pontoon to be brought up. He gets into it, and from it superintends its passage to the bridge-head.

G.C, G.3., G.4., G.5., G.6., G.7. each move into the next pontoon, G.1. and G.2. remaining

NOTES.

No button-baulks are brought up when E detachment leads.

In order to avoid crowding the baulks are brought up in two ranks at all times, the odd numbers forming the front rank, the even numbers the rear rank. The even numbers cover the intervals between the odd numbers, thus :—



As soon as the officer in charge sees that the shore ends of the baulks are fixed, he gives the command "CHESSES," when chessing can be completed for the first bay—7 feet.

F.C. always stands at the chess pile and issues chesses.

E.C. always carries the last chess.

The chesses are brought up 15 at a time and laid double. The last chess of the odd numbered bays, and the last two chesses of the even numbered bays are turned back to leave the saddle-beam clear, as in Medium Bridge.

standing on the thwarts and saddle-beam after laying the last chess. These eight numbers prepare to receive baulks.

3rd bay. BAULKS. E.1., E.2., E.3., E.5., E.6., E.7., F.1., F.2., F.3., F.5., F.6., F.7. bring up six plain baulks. E.4. and F.4. bring up one riband.

The numbers of E detachment lead and the baulks are brought up in two ranks as before.

G.C., G.7., G.3., G.4. receive the ends of these baulks and place them in their proper cleats. G.1., G.2., G.5. and G.6. assisting at the saddle of their own pontoon.

When the outer ends of the first four baulks are chocked, the numbers of E detachment push out as necessary and place the baulks in the cleats of No. 1 pontoon. S.4. is responsible that the ends of the baulks are placed in their proper cleats. The remaining baulks of the rear rank are then placed.

CHESSES. G.1. and G.2. get up on to the baulks and lay the last chess of the previous bay.

H.C. gets into the fourth pontoon and guides it to the head of the bridge.

G.C., G.3., G.4., G.5., G.6., G.7. each move into the next pontoon; G.C., G.7., G.5., G.6. dealing with the cables in their respective pontoons as may be necessary.

F.C. goes to the chess pile. The numbers of E and F detachments as previously detailed bring up a chess each. The first chess is laid on top of the last chess of the previous bay, the remainder of the chesses are laid double. The last two chesses are turned back.

4th bay. BAULKS. F.1., F.7., E.1., E.7. bring up two button-baulks.

F.2., F.3., F.5., F.6., E.2., E.3., E.5., E.6. bring up four plain baulks. F.4. and E.4. bring up one riband.

The numbers of F detachment lead.

CHESSES. G.1. and G.2. get up on to the baulks and lay the last two chesses of the previous bay.

The chess numbers as before detailed bring up the chesses, and the last chess of this bay is turned back.

H.C. brings up the fifth pontoon, and G.C., G.3., G.4., G.5., G.6., G.7. move, as before detailed.

5th bay. BAULKS. E.1., E.2., E.3., E.5., E.6., E.7., F.1., F.2., F.3., F.5., F.6., F.7. bring up six plain baulks. E.4. and F.4. bring up one riband.

The numbers of E detachment lead.

NOTES.

As soon as the officer in charge sees that the ends of baulks are fixed, he gives the command "CHESSES," when chessing can be done for the second bay.

Making barrel piers.

Description of stores.

111. To make bridges of barrels the barrels must first be formed into piers. The piers are then formed into bridge in much the same way as pontoons would be.

Barrel piers can be formed of any number of casks from two upwards, any available material being used to connect them.

The following stores are used at the S.M.E., Chatham :—

Barrels, common butt and hogsheads.
Gunnels, 21 feet long, 4″ × 5″. The centre of each gunnel is marked with paint or a saw-cut.
Slings, 2½″ rope with eye-splice at one end 12 inches long; gross length of rope, 6 fathoms.
Braces, 1½″ rope, 3 fathoms long, with small eye-splice at one end and figure-of-eight knot 1′ 5″ from the eye.
Tie-baulks, 15 feet long, 3″ to 4″ diameter or square, the central intervals between piers being marked by two marks equidistant from the ends.
Tie-baulk lashings, 1″ rope, 3 fathoms long.
Baulks, 14 feet to 15 feet long, 5″ in diameter or 6″ × 4″.
Chesses, as for pontoons.
Anchors, about 1-cwt.
Ways for launching piers formed of two side pieces (Pl. LXXXI., Figs. 5, 6 and 7) fitted with way-ropes similar to the braces.

Forming piers.

112. In forming the piers (Pl. LXXX., Fig. 1), the barrels are laid out in line, bungs uppermost, the gunnels placed over their ends, and the slings are then secured under the ends of the barrels and to the gunnels. Between each pair of barrels, on each side, a brace is secured to the sling, and is then led round the gunnel; the opposite braces are crossed, and secured again on their own side. The pier is then launched into the water.

Men required.

113. The number of men required to make a pier of n barrels is $2(n+1)$, divided into two detachments. Thus, to make a pier of seven barrels, two detachments of one commander and seven men each are required.

114. The following exercise answers for making piers of seven barrels each, which, if butts at central intervals of 10 feet, are suitable for bridges carrying infantry in fours crowded at a check, and field guns (para. **35**).

Stores for one pier.

The stores required for one pier are as follows :—

7 barrels.	12 braces.
2 gunnels.	2 breast-lines.
2 slings.	1 boathook.

115. The working party falls in in column of detachments of a commander and seven men each, with the water on their left.

Each detachment is in single rank, with its commander on the left:—

Forming barrel piers, in slow time.

LETTER YOUR DETACHMENTS FROM THE FRONT. The commanders take a pace to their front, turn to their right, and letter their detachments, and then fall in again.

A AND B DETACHMENTS—NO. 1 PIER.

C AND D DETACHMENTS—NO. 2 PIER.

A AND C—FRONT DETACHMENTS.

B AND D—REAR DETACHMENT.

DETACHMENTS, NO. 1 PIER—STAND AT EASE.

DETACHMENTS, NO. 2 PIER—STAND AT EASE.

FRONT DETACHMENTS—ATTENTION.

REAR DETACHMENTS—ATTENTION.

FROM THE RIGHT OF EACH DETACHMENT—NUMBER.

COMMANDERS AND NOS. 1, GUNNEL MEN. REMAINDER, BRACE MEN.

GUNNEL MEN, PROVE. The gunnel men are proved (para. 3).

BRACE MEN, PROVE. DOWN. The brace men are proved.

PREPARE TO FORM PIERS. The gunnel men bring up two gunnels for each pier and lay them outside of the position of the piers, *i.e.*, perpendicular to the bank, and parallel to the piers; Nos. 2, 3, 4, and 5 front detachments, and 2, 3, and 4 rear detachments bring a cask each, and place them in line between the gunnels with their bungs upwards; Nos. 5 rear detachments bring two breast-lines and a boathook each, and place the breast-lines one at each end of each pier, and the boathooks on the ground at the shore end of the casks; Nos. 6 bring 6 braces each, uncoil them, and distribute them on their own sides of the casks, with the eyes close to and outside the gunnels; Nos. 7 bring a sling each, and place them with the loop towards the river, under the ends of the cask, and on their own sides of them.

The men then fall in on their own sides of the casks, turning inwards, the brace men opposite the intervals.

LINE CASKS. The whole of the odd numbers, except Nos. 1 of the rear detachments, place the forefinger of the right hand perpendicularly on the bung of the cask to their own right, and the even numbers are directed to move the casks till the bungs are in line, the commanders of the front detachments lining them.

STEADY. The fingers are removed and all stand at attention.

GUNNELS. The brace men stoop down, the gunnel men lift the gunnels, and place them on the casks about 4 inches from their ends, and with the centre mark over the centre of each pier; as soon as the gunnels are on the casks, brace men spring up and place both hands on the gunnels to keep them in their places while the slings are being fixed.

If the casks do not all touch the gunnels, they must be packed up underneath, care being taken to preserve the alignment of the bungs.

SLINGS The commanders take up the loops of the slings, pass them over the ends of the gunnels. Nos. 1 then take up the other ends, and, facing the commanders, haul taut by placing their inward feet against the end casks, and hauling, they then bring up the slings by the inward sides of the gunnels, take a round turn, and make fast with two half-hitches. The brace men take care that the slings are under the casks, pushing them under with their feet, if necessary. The two ends of the slings must be vertical.

When the slings are fixed, the gunnel men stand at the ends of the gunnels, and hold them steady with both hands.

BRACES. Each brace man takes up a brace; he takes the eye in his left hand, and passes it under the sling in the centre of the interval between two casks, draws the end through the eye, and placing the left foot on the sling to prevent its being moved, hauls his brace taut down to the eye, then coils up the brace, holds it in his right hand, and removes his left foot from the sling.

TAKE A TURN. Each brace man takes a turn with his brace to the *left* round the gunnel, exactly over the eye of the brace, and throws the coil behind him to his own right rear.

HEAVE AND HOLD ON. Each brace man hauls up the standing part of his brace with his left hand, and holds on with his right by the turn. When the brace is taut, he places the heel of his left hand on the turn, and coiling up the brace holds the coil in his right hand.

CROSS. Each brace man places his coil on the cask to his own *left*, using the right hand only.

TWO.	Each brace man takes the coil of the man opposite to him from the cask to his right, and passes it between the standing part of his brace and the cask to his *left*.
THREE.	Each brace man passes the brace back between the standing part of his brace and the cask to his right, and places it on the cask to his right, taking care that the turn of the brace is below the knot.
FOUR.	Each brace man takes his own brace from the cask to his *left*, and passing it under the gunnel to the *left* of the standing part, holds on to it (Pl. LXXX., Figs. 2 and 3).
PREPARE TO ROCK AND HEAVE.	The brace men take a short pace backwards, place the left foot against the gunnel, and take in the slack of their braces.
ROCK AND HEAVE.	The rear detachments haul on their braces, the front detachments push with their left feet, holding their braces taut, the gunnel men assisting to move the pier; then the front detachments haul, and the rear detachments push holding their braces taut, and the pier is thus rocked backwards and forwards.
STEADY.	The brace men remove their feet from the gunnels and haul their braces taut.
TAKE A ROUND TURN.	The brace men take a round turn to the *left*, and hold it down with the heel of the left hand.
MAKE FAST.	The brace men take two half hitches round the two parts of their own braces close to the gunnels, drawing the two parts close together, and place the spare end of the braces between the casks; the whole then stand at attention (Fig. 3).
PREPARE TO TURN PIERS TO THE RIGHT.	The front detachments place both hands on the gunnels, the rear detachments stoop down and take hold of the casks.
TURN PIERS.	The rear detachments lift, the front detachments haul on the gunnels till the casks stand on end.
FIX BREAST-LINES.	The commanders and Nos. 1 of the front detachments each take a clove hitch with a breast-line round the upper and lower slings respectively, close under the gunnels at their own ends of the pier.
ADJUST SLINGS.	The brace men see that the slings are straight, and just below the third hoop of the cask; if they are not so, they adjust them.
PREPARE TO LOWER PIERS.	The front detachments stoop down, and place their hands under the gunnels, the rear detachments take hold of the tops of the cask.

LOWER PIERS. The front detachments lift, and the rear detachments haul, and as the piers come to them, they shift their hands to the gunnels to ease the piers down, and all stand at attention.

PREPARE TO TURN PIERS TC THE LEFT. The front detachments stoop down and take hold of the casks, the rear detachments take hold of the gunnels.

TURN PIERS. As before.

ADJUST SLINGS As before.

GUNNEL MEN—BRING UP WAYS. The ways are brought up by the gunnel men, and placed close behind the front detachments, who must stand close in to the casks.

Care must be taken that the way-ropes are clear.

PREPARE TO LOWER PIERS. The rear detachments stoop down and take hold of the gunnels, the front detachments take hold of the top of the casks.

LOWER PIER. The rear detachments lift, and the front detachments haul the casks towards them, shifting their hands to the gunnels as the piers fall, to ease them down on to the ways, and all stand at attention. The commanders and Nos. 1 of the front detachments place the coils of the breast-lines on the end casks, and Nos. 5 rear detachments place the boathooks on the shore ends of the piers.

MAN WAYS. Nos. 2 and 3 man the rear, Nos. 4 and 5 the centre, Nos. 6 and 7 the front way ropes, and haul them taut towards the river, commanders and Nos. 1 lay hold of the piers to push them forward.

LAUNCH. The whole of the men haul and push the piers till they are at the water's edge, when Nos. 6 and 7 let go their ropes; the commanders then take hold of the breast-lines on their own sides of the piers, Nos. 1 front detachments take the boathooks, and when the other men have pushed the piers as far into the water as they can they push them off till they float.*

WAYS TO THE REAR. Nos. 2 haul on their ropes, assisted by the other men as soon as the other ropes are drawn out of the water; all double up with the ways, which are to be placed ready for use again. All the ropes clear.

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* If the ground be at all soft, the men at the front way-ropes must hold on as close to the piers as possible, so as to lift the front of the ways, and in very soft ground, pieces of wood, such as old oars, spars, planks, &c., should be placed at right angles to the ways to prevent their sinking, and if such pieces of wood are wetted, the ways will run on them all the more easily.

When the piers are to be landed, if there are no spare men to attend them, and keep them straight on the ways, Nos. 1 front detachments will perform that duty.

Dismantling barrel piers in slow time.

BRING THE WAYS. The gunnel men double up for the ways, and bring them down to the water's edge. Nos. 1 get on the piers; Nos. 1 of the front detachments with the boathooks bring the piers to the spots where they are to be landed, Nos. 1 rear detachments cast off the off-shore breast-lines, and make them fast to the in-shore ends, so that there may be two at the same end of each pier and one fast to each sling.

MAN BREAST-LINES. The brace men take hold of the breast-lines on their own sides, and open out to the right and left, so as to assist in keeping the piers straight.

DIP THE WAYS. Nos. 2 and 3 lift up the shore ends of the ways, and launch them so as to go under the piers, as far as they can push them. They then place their feet against the ways to prevent their being moved by the piers.

BRACE MEN HAUL. HALT. The brace men haul on the breast-lines, till the command "Halt" is given, when Nos. 1 will jump off the piers. The end casks should now be over the shore ends of the ways.

MAN WAYS. The way ropes are manned as in launching. The commanders and Nos. 1 of the front detachments cast off the breast-lines.

TOGETHER—HAUL. HALT. All haul together, and run the piers up out of the water. The men lay the ropes down close alongside the ways, and fall in in their places on the piers at once.

PREPARE TO TURN PIERS TO THE LEFT. As before.

TURN PIERS. As before.

REMOVE WAYS. The gunnel men remove the ways and fall in again in their places.

PREPARE TO LOWER PIERS. As before.

LOWER PIERS. As before.

DISMANTLE. Each man undoes what he did, and coils up all the ropes neatly. Nos. 1 coils up the breast-lines, Nos. 7 the slings, brace men their braces, and when done all stand at attention.

REMOVE GUNNELS. The brace men stoop down, and the gunnels are carried away by the gunnel men.

REMOVE STORES. The stores are taken up by the men who brought them down.

Forming cask piers, quick time.

116. When the men are all expert at working in slow time the piers may be formed in quick time by words of command without numbers or preparatory cautions.

The forming of barrel piers into bridges is dealt with in Sec. XIV.

The various operations of forming rafts, forming bridge from rafts, swinging and forming cut, are performed in the same manner as already described in Pontoon Drill.

SECTION VIII.—BRIDGE ENDS AND TIDAL RAMPS.

1. It is often necessary to make the ends of floating bridges on a slope on account of the height of the banks above the water.

In some instances the level of the water will be constant; in tidal rivers it will be continually changing; while in non-tidal rivers the effect of droughts and floods may be sufficient to cause a considerable variation in level.

Tidal ramps.

2. Where there is a large tidal variation the construction of the bridge ends, in order that they may be at all times available for traffic, requires much ingenuity, time, and labour, and may be impracticable for hasty operations.

The most usual cases will fall under the following heads :—

(1) When the bank or shore falls at a gentle slope not steeper than 1 in 7.

(2) Where the banks are steeper than 1 in 7 but still sloping.

(3) Where the bank is vertical or nearly so, but with a bottom available for trestles or piles.

(4) Where the bank is vertical or nearly so and the water so deep that only floating supports can be used.

3. (1) The case of the gentle slope presents little difficulty provided the piers are strong enough to carry the load when grounded. If the bottom is irregular or contains projections which might injure the pier, it must be levelled and the obstructions removed, or if this is impossible a cradle in which the pier may rest must be constructed. These may be made of reeds, brushwood, or sacks of earth. The slope 1 in 7 is just passable for all arms, but a flatter slope is desirable. This may be arranged by building up these cradles to such a height as will give the desired slope. (Pl. XXV., Fig. 1.) The slope, as a rule, should not be steeper than 1 in 10.

4. (2) With a steeper slope, a similar construction of larger cradles may suffice or a modification of one of the following methods will be adopted.

5. (3) With a vertical bank, but with a bottom available, a structure composed of trestles, either with adjustable transoms, or which are bodily lifted by floating piers as the water rises becomes necessary, if the bridge is required for wheeled traffic.

For infantry traffic alone, the provision of a long gangway, the off-shore end of which is allowed to slide on the roadway of the floating bridge, will suffice. With such an arrangement the gangway should have battens nailed across its floor and handrails must be provided, and a much steeper slope will be permissible than in other cases. (Pl. XXV., Fig. 4.)

For wheeled traffic, however, the gangway or ramp should be given intermediate supports which will prevent the slope becoming too great and this may be accomplished by constructing trestles, the transoms of which can be raised or lowered as required.

The service trestle is convenient for this purpose and can be used in a self-acting tidal ramp as shown on Pl. XXVII. This is best made at high water, the trestle transoms resting on rafts and their intermediate bays, and the legs shortened.

As the tide falls each bay will tilt in succession, and the legs of the trestles can be lowered and allowed to take the bottom as each successive bay tilts to its proper inclination; as the tide rises each raft will pick up its trestle in succession.

Four men are sufficient to attend to a tidal ramp of this description; they can lower the legs of the trestle in succession as the tide falls for the first time after the construction of the bridge, and on a rising tide they adjust each raft successively as it is on the point of lifting its trestle.

If the bridge may have to be swung it is necessary to provide means for disconnecting the floating portion of the bridge from the trestles. This can be done by using the special equipment for "cuts" (Sec. VII, para. **97**).

Pl. XXV., Fig. 5, shows a trestle with an adjustable transom. It consists of double legs between which the transom moves. At the head of the legs are cross pieces to which are attached the tackles used for moving the transom and for supporting the load. Trestles of this nature 33 feet over all have been successfully employed on a muddy bottom with a 14 foot rise and fall of tide, but they are cumbrous to handle owing to their weight, and are best placed by the distance frame method explained in Section X, para. **7**.

Such arrangements require men constantly on duty at the tackles, and to obviate this, an automatic ramp may be improvised. These will usually consist of a combination of trestles and floating piers so arranged that at certain states of tide the trestles take the ground and support the load on their transoms which are adjusted to the correct slope.

The floating piers being freed from the load, may now safely take the bottom. As the water rises, the floating piers raise the roadway, the trestles being left on the bottom or being lifted with the roadway whichever is most convenient.

In all cases where trestles are supported on floating piers they should each be carried by a pair of piers, to ensure stability.

These must be securely anchored and should rise and fall between guides to prevent them from becoming displaced. The anchor cables will require constant adjustment if there is a strong current. The weight of superstructure and traffic must in all cases be carefully estimated and the pier employed should have a greater margin of buoyancy than is ordinarily allowed.

An alternative to a ramp passable to all arms would be an infantry bridge combined with rafts for vehicles and animals. Pier heads would be provided for the rafts consisting of a permanent roadway ending in a lift adjustable to the height of water. Vehicles are then ferried over in the raft transferred to the lift, and by it raised to the pier level. Cut baulks being used to connect rafts to lift and lift to pier. (Pl. XXVIII., Fig. 1.)

This arrangement, however, would not be possible where the banks are very high owing to the difficulty of construction of the lift. The falls of the tackles could be adjusted to length when a team of horses could be used to apply the power without risk of tipping the raft.

6. (4) Vertical banks combined with no available bottom represent the most difficult case, and the material available will dictate the arrangements to be made. Trussed beams or girders with one end sliding on the roadway of the bridge would be suitable (Sec. IX, para. **2**).

Another alternative is to support the transoms for the roadway on tripods carried on rafts, each tripod being provided with tackles (or other gear) wherewith to raise or lower the transoms, so that the ramps may not have a rise at high water, or a fall at low water steeper than the greatest admissible slope.

It is impossible to definitely lay down a type ramp, and usually several of the above methods will have to be combined in one ramp.

Pl XXV., Fig. 1, shows an example. In it the piers E and F float at high water while at low water they rest on cradles adjusted to height to suit the slope of the roadway. Transom G at low water is supported by slings attached to a suitable framework, while the fourth transom is supported on a fourlegged trestle at low water, which trestle is picked up when the tide flows by a two-pier raft.

Pl. XXV., Fig. 5, shows a ramp supported on trestle transoms. At A is a two-legged trestle with a fixed transom, to which the roadbearers are fastened, the head of the trestle being secured to two bollards. At B are two three-legged trestles (the third leg is omitted in the figure). These are equipped with tackles. The falls from the tackles are taken ashore, and the transom raised or lowered by their means. A crosspiece P may be added to receive the transom when in its lowest position. By allowing the roadway to have a rise from A at high water the amount of variation from the horizontal is nearly halved. At C the supports are similar, but must be weighted or picketed down to prevent them floating at high water when relieved of the weight. At high tide this weight is taken by a bay of the raft D. This bay is not chessed but its baulks have to take a central concentrated load made up of the traffic and the superstructure; they must therefore be stronger or more in number.

The ramp is completed by a high saddle at D and its end finally slides on the roadway. The position of the transom D with respect to the baulks of the supporting bay is important as it determines the necessary strength.

Pl. XXVI., shows a ramp composed of composite trestles with adjustable transoms terminating in a ramp raft. This combination was employed on the dockyard end of a bridge across the Medway at Upnor.

Pl. XXVII. shows how service trestles and pontoon equipment may be combined to form a tidal ramp.

The elongation and contraction of the bridge at the varying states of tide must always be remembered and allowed for.

This is usually done by employing sliding baulks rigidly attached to the saddle beam of one pier and free to slide on the saddle of the next.

The total elongation should be distributed over several bays. Rope ties should be used to prevent any risk of one bay contributing more than its share to the total elongation.

Use of rafts.

7. Rafts would generally be used under one of the following conditions: —

(1) When there is insufficient material for the construction of a bridge.
(2) When it is only necessary to establish a ferry.
(3) When material too heavy for a bridge has to be conveyed across a river.
(4) For the transport of personnel and material along waterways.

Construction of rafts.

8. They may be made of boats, barrels, or of timber, though pontoons are the most convenient. Rafts for light loads may also be constructed out of improvised material (Sec. XIV).

In constructing a raft composed of three piers with a waterway between, it must be remembered that the central pier is more heavily loaded than those on either side unless very stiff continuous baulks are used to distribute the load.

Rafts for heavy concentrated loads should be stiffened by the use of stout roadbearers such as rails, while rafts of one pier should only be loaded over the centre quarter of their area.

Animals always tend to crowd towards the centre, however carefully spaced at starting. Screens which prevent animals seeing the water are always desirable, but may have to be dispensed with in a wind.

Methods of moving rafts.

9. Rafts may be rowed, poled, or towed, or in the case of a river hauled backwards and forwards by ropes, or they may be moved across the stream by the action of the stream described later.

Rafts are very difficult to manage in rapid streams even when made of boats or pontoons, while they usually present a large surface to the wind. They are generally most easily moved by towing. If towed from boats, two towlines should be used or the towline should be made fast by means of a "bridle."

Towing.

10. If two boats are towing a raft they should always tow "line ahead" and not take a line each from the opposite corners of the raft. The heavier boat should be next the raft. Boats crews engaged in towing do not "lay on" or "toss" oars as a salute. Short towlines are best for slow speeds, and the raft must always be steered.

If towed from the bank a tow mast will usually be required to prevent the towline fouling obstructions on the bank. When rafts are towed by horses towing traces will be necessary. These can be improvized from the ordinary "traces saddlery." Smooth oval wooden reels should be threaded on the traces to prevent the flanks of the horses being galled and the traces should be kept apart by means of a spreading bar or swingle-tree.

A method of towing a heavy raft of more than one boat is shown on Pl. XXX., Fig. 2. The towline ACD is fixed to the bows of the in-shore boat, an "adjusting line" BC is fixed to the towline at C (AC = AB), the other end being held at B by means of a tackle. The raft will sheer in-shore or off-shore according as the "adjusting line" is hauled in or paid out at B.

Transport rafts of large deck area.

11. Rafts of large deck area for transport of men and material can conveniently be made with the Service Pontoon equipment, by forming long boats consisting of any number of sections coupled up together, a bow piece being at one end or both ends and all other sections being stern pieces. The boats are then formed into a two or three-boat raft. The saddle and superstructure can be continuous from end to end.

If, as is probable, the number of bow and stern pieces available are equal, each raft would be made of boats each consisting of two bow pieces and two stern pieces, the bow pieces being, of course, at the stem and stern of the raft.

Any convenient number of such rafts could be fastened together in column for towing. If this is done the rafts should be enclosed by a cable to which all the rafts are made fast, and which is connected to the tow lines. The fastening together of a column of rafts by means of connecting the belaying cleats at the stern of one raft to that in the bows of the next raft throws too much strain on the pontoon couplings of the leading raft, and they are liable to tear out.

If a large deck area is not required, the pontoon equipment can be most advantageously used in the following manner:—

First remove the saddles and couple together as many sections as may be required, forming two (or three) long boats with bow-pieces at one or both ends. Place the boats side by side and lash them together as in Pl. XXVIII., Fig. 2.

Light stores, such as ropes, &c., may be placed in the pontoon, but such stores as anchors and picks should not be placed in the pontoons as they tend to injure the bottoms.

Chesses are now laid over the thwarts and gunwales, forming one continuous deck from bow to stern, leaving a small space at each end for steering and other purposes. Such a raft has great stability and carrying power, and is very easy to steer and manage.

Such rafts are best moved by towing.

Four oars can, however, be used on each raft for rowing, and the rafts can be punted along by using poles from small footways made along the sides and from the ends of the raft.

If the raft is for use in swift running water or where efficient control is required, saddlebeams should be fixed on the outer lengths of pontoons, and the decking stopped over them, so as to leave room for the rowing numbers to sit on the thwarts and to use the rowlocks.

Calculation of deck space required.

12. Deck space required on rafts should be estimated from the following dimensions, which are based on plan dimensions and which allow for projections except where stated :—

	Length.	Width.
Armed man sitting	3′ 6″	2′ 3″
18-pr. gun	14′ 6″	6′ 3″
„ limber	5′ 9″*	6′ 3″
G.S. wagon	13′ 9″*	6′ 1″
Wagon, limbered, G.S. ...	5′ 7″*	6′ 4″
60-pr. B.L. (travelling position)	16′ 6″	7′ 0″
Limber	7′ 0″*	7′ 0″
Horse, harnessed	8′ 0″	4′ 0″

Rafts for the transport of troops and vehicles.

13. The bridging equipment of one field company, R.E., is sufficient to provide for a raft of two pontoons, two landing piers 15 feet long, and a landing gangway.

The raft is made as described in Sec. VII, para. **87**; and, if intended to carry animals, must be fitted with rails to prevent accidents (Pl. XXVIII., Fig. 3). The rails are baulks lashed to chesses up-ended, which are lashed to the saddle-beams. The ends of these chesses must not be allowed to bear directly on the bottom planks of the pontoons.

Each landing pier consists of a shore-end, a service trestle, and one bay of superstructure.

The landing gangway is required to connect the raft with the landing pier. It is made as follows :—

Five baulks are placed across the gunwales of one of the pontoons, under the superstructure. To these baulks, underneath them, and 2 feet from the outer cleats, is lashed another baulk.

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* Exclusive of pole.

This frame, thus made, forms a sliding bay, which is used to connect with the pier in much the same way as cut baulks connect the cut-raft with the bridge (Sec. VII, para. **97**).

Eight chesses should be kept at each landing pier to complete this bay when required.

The stores required, and their proper allotment, are as follows :—

	Total carried in bridging equipment of one Field Company, R.E.	Required for two landing stages.	Required for the two-boat raft.	Required for connecting raft to landing-stages.	Remarks.
Baulks plain	15	6 R	3 R	6 R	R = roadway.
Baulks, button ...	10	4 R	2 R 4 H	—	H = handrails.
Baulks, shore-end, inside, sets	2	2	—	—	a = strut lashings.
Baulks, shore-end, outside, sets	2	2	—	—	b = handrail lashings.
Chesses...	81	36	15 R 8 H	16	c = warping lines.
Ribands	10	4 R	2 R 4 H	—	d = foot-ropes to trestles.
Cordage, $1\frac{1}{2}''$, of 10 fathoms, lashings ...	10	4 a	4 b 2 c	—	
Lashings, $1\frac{1}{2}''$ of 30' ...	10	4 d	4 b	2	

The loads which the rafts may be expected to carry in smooth water, including a crew of four men, are :—

Infantry.—Fifty fully-armed men ; or
Cavalry.—Six horses and their riders ; or
Artillery.—Three drivers and six draught horses ; or
Six gunners and one driver, one gun, one limber, one riding horse ; or
One gunner, one driver, one wagon, two draught horses (Pl. XXIX., Figs. 2, 3 and 4).

The infantry should sit down on the edge of the raft, as close as possible. The remainder can then sit in the central portion of the deck.

14. If the equipment of two field companies, R.E., is available, it is sufficient to provide one four-pontoon raft, two landing piers, and two landing gangways.

The raft is made as follows:—

Two pontoons are joined end to end to form each pier, their saddle-beams being joined so as to be continuous over the two pontoons. Baulks are placed at the usual intervals, the decking being formed of three rows of chesses; a deck of 15′×22′ 6″ is thus provided. A portion of the third row of chesses is unsupported and must not be used. When chesses butt, other chesses must be laid across the joint and lashed down to them.

To check any tendency of these long piers to buckle, three baulks lashed together lengthways are lashed across the thwarts of each pair of boats to act as stiffeners.

If animals are to be carried, rails must be provided as described for a two-pontoon raft, the same precautions being taken to prevent damage to the bottoms of the pontoons.

The landing gangways are made as described for the pontoon rafts; but in this case are worked from the landing piers, and not from the raft as improvised cut-baulks.

The stores required for a four-pontoon raft are as follows:—

	Roadway.	Handrails.	Ribands.	Stiffeners.	Total.	Remarks.
Pontoons	—	—	—	—	4	
Saddles	—	—	—	—	4	
Baulks, plain ...	9	4	2	2	17	
Baulks, button ...	5	4	—	1	10	
Ribands	1	4	—	3	8	
Chesses	45	—	4	22	71	
Rack lashings ...	—	—	—	—	3	
Lashings of sorts ...	—	—	—	—	34	

The loads this raft may be expected to carry in still water are:—

Infantry.—100 men. There is a great tendency to buckle, and, therefore, the pontoons must be carefully stiffened; or

Cavalry.—Twelve horses and their riders; or

Artillery.—Six drivers and twelve draught horses, or one officer, seven gunners, one driver, three riding horses, one gun, one limber, one wagon, one limber.

Freeboard of 10 inches allowed. (Pl. XXIX., Fig. 1.)

Pl. XXX., Fig. 1, shows a raft suitable for carrying a 60-pr. B.L. gun.

The pontoons should be placed at 7-feet 6-inch intervals, and the deck formed with nine baulks to each bay, double chessed.

Stores required:—

Pontoons	4
Baulks, plain	18
Ribands	4
Rack lashings	12
Chesses	46

Freeboard, 10 inches.

General instructions.

15. Two-pontoon rafts are more easily and rapidly constructed than four-pontoon rafts, are much more easily handled, and more suited for continuous work.

If more than one pontoon is to be used in a pier, great care must be taken to place the load so that there is the minimum tendency to buckle, and stiffening baulks must be provided.

Three-boat rafts when loaded are unmanageable in a stream, and are not recommended.

The transom of the landing piers should be adjusted so that it is not higher than the saddle-beam of the *loaded* raft.

When adjusting the landing gangways, and when rowing the raft, it is usually necessary to remove the end chess immediately over the saddle. If the raft is fully loaded with horses, the chess cannot be removed with safety unless an additional baulk is lashed, low down, on the inside of each handrail.

The lashings must be constantly watched if the rafts are in use for a long period.

Rafts carrying horses and vehicles are liable to be affected by wind, and are more difficult to manage than those on which the load is placed low. Except in very favourable circumstances these rafts should be towed or warped across the stream.

Pier heads.

16. Pier heads in important situations would be made of piles driven by one of the methods described in Sec. X. But occasions may arise when a more rapidly constructed pier is required. In this case a floating pier would be used.

Service pontoon equipment lends itself readily to the construction of piers and the general arrangement is shown in Pl. XXXI., Figs. 1 and 2. The pontoon sections are coupled together so that a bow piece may be at the end of each row of pontoons, the intermediate sections being all stern pieces. The saddles should be continuous throughout each pier. Spare bow pieces can be utilized in the approach.

The main points to be noted are that the baulks should slightly overhang the sides of the outer pontoon, and the outer chesses must be securely lashed in case they are held on to with boathooks. The chesses placed over the ends of the chesses of the pier-head floor must be very carefully racked down and attended to while the pier is in use.

If heavy vessels are to come alongside the pier the baulks should be lashed to the saddle-beams of the pontoons, otherwise, should the vessel bump the pier, they will jump out of the cleats, and the pier will be in danger of telescoping, or the claws torn off the baulks. In the figures they are shown only in the intermediate cleats. If considered necessary, baulks can be placed in all the cleats. In the figures they are shown only in the intermediate cleats when necessary to support the ends of the chesses.

If the pier is for use with a pontoon raft, cut baulks are the simplest and most satisfactory means of connecting the roadway of the pier to the deck of the raft. In this case the chesses will only be carried as far as the outer saddle-beam. Good fenders should be kept at hand or used to protect the sides of the outer pontoons at the pier head.

The anchoring of pier heads is a matter of great importance, and it should be borne in mind that these anchors must hold not only the pier itself but also the boats or vessels using it. If steam pinnaces or launches are to call at the pier, care must be exercised in laying out the anchor cables so that a fairway for approach is left, otherwise much delay and possibly danger will be caused by the propellers of the boats fouling the cables. On this account it is also advisable to omit buoys and buoy-lines at the pier head anchors.

Flying bridges.

17. By a proper management of the cables, especially of the stream cable, rafts at anchor may be moved or *sheered* across the current for some distance. In a moderate current, the men hauling on the stream cable should always stand at the head of the raft in the centre between the piers, but in a strong current they may have to move about from one position to another. For instance, if the current has caught the port pier and brought the raft round with the starboard pier broadside to the stream, the men with the stream cable should stand over the port pier as near the head of the raft as possible. This will soon bring the raft square, when they should move smartly to the centre of the raft again. Similarly, if the raft is swung round with the port pier across the stream, the cable men should stand over the starboard pier at the head of the raft. The operation will be assisted by the lower cable being kept hand-tight, and the men holding it moving into the opposite corner of the raft to that where the men stand with the stream cable, and coming again to the centre of the raft when it is square. Sheering rafts.

18. A *flying bridge* is one in which the action of the current is made to move a boat or a raft of two piers across the stream, by acting obliquely against its side. The side of the boat or boats should be kept at an angle of about 55° with the current. (Pl. XXXIII., Fig. 1.) Flying bridge.

In every case it is desirable to use long narrow deep boats with vertical sides, to which lee-boards may be attached; a raft of two boats is best; the weight of the boat or boats should be considerable as compared with that of the cable; flexible wire cables are the most satisfactory.

A lee-board can be extemporized from two or three chesses or planks held together by battens nailed to them, or nipped between two boathooks or light poles. Its end must be held down by a lashing under the boat, or by a heavy weight lashed on to it. In any case it should be easy to raise it quickly. (Pl. XXXII., Figs. 8 and 9.)

19. Wind interferes very greatly with the working of flying bridges and may easily make them unworkable. The action of the current on the lee-board causes the raft to tilt. The depth of the lee-board must therefore be no more than is required to move the raft, otherwise in a strong current there is a danger of the pier to which the lee-board is attached being swamped. A spare anchor and cable should always be kept on board in case the swinging gear breaks.

Straight reaches are generally the most suitable parts of rivers, being most free from irregularities of current, and backwaters. In selecting the site, it is well to see the river when in flood. At all times a velocity of at least two miles an hour is wanted. Much trouble is saved by forming landing stages of trestles, boats, &c. Ramps which can be raised and lowered are convenient at each end of the raft; they may be made to counterbalance by being connected by a pair of ropes, each running on a pair of pulleys supported on two props, one at each end of the platform of the raft. A ramp is lowered by men walking on it, thus at the same time raising the other.

20. Flying bridges sometimes hang as they near the banks; a line, buoyed in their track and attached to the pier may, in such case, be used to pull them in.

There are three ways of working flying bridges:—

(1) By using a suspension cable.
(2) By using anchorages and swinging cables.
(3) By using a warp.

Flying bridge with suspension cable.

By the first method spans of over 400 yards may be crossed by using wire cables (which are always best). (Pl. XXXIII., Fig. 1.)

A post is set up on solid ground on each bank, and well tied or strutted; the top has a cap with a grooved bearing for the cable to rest in. The cable is got over, raised, and anchored, as described in suspension bridging (Sec. XI.); it should be stretched as taut as its strength will allow, and the centre of the curve should be well above the highest flood level. As the steepest parts of the curve are near the piers, these should be placed as far back from the banks as the strength and length of the cable will permit; the pulleys (Pl. XXXII., Figs. 1, 2 and 3), to which the raft is attached, and which runs on the cable, has then to travel on the central parts of the curve only. Two lines are attached to this pulley and to the raft; the length of the longer line can be varied as required, and for returning it is shifted to the other side. Sometimes two pulleys are used as shown at B. The suspension cable can be hauled up when necessary as described in Sec. XI., para. **11**.

It has been found by experiment that with a dip of about $\frac{1}{17}$th of the span, an oblique pull at the centre of the cable, at a slope of $\frac{1}{4}$, caused a tension in the cable of from $\frac{2}{3}$ to $\frac{3}{4}$ that produced by the same pull when acting vertically. The pull due to the raft being known, it will be safe to consider it as a concentrated vertical load, and calculate the stress in the cable by the formula in Sec. VII., para. **18**. Stress on the cable.

21. In bridges with a swinging cable the length of the cable should be about $1\frac{1}{2}$ to 2 times the breadth of the river, and if the cable be long it must be supported on intermediate buoys or floats (Pl. XXXIII., Fig. 2), or better still, on masts placed in the bows of boats so as to prevent the cable dragging in the water; or it may be carried as shown in Pl. XXXII., Figs. 4 and 5. Whatever type of float is used on the cable the pattern adopted must be quite stable. A series of small floats at close interval produce better results than a few large ones. The latter interferes with the swing of the cable and causes the raft to hang as it nears the shore. The cable end is secured near the middle of the flying bridge, and the boat or boats are steered, or else the cable is fastened to a bight of a rope, the two ends of which are secured as in Pl. XXXIII., Fig. 2. This rope is about three times the boat's length, and the two ends are taken in or let out, to give the required inclination to the current. Flying bridge with swinging cable.

The boat floating support nearest the anchors should be moored. Two or three pontoon anchors may be used together for an anchorage, their shanks being laid parallel to the central and extreme directions of the cable as it swings (Fig. 2). An alternative method of mooring is shown in Fig. 3. This method permits the cable boat to be moved across the stream as the raft nears the banks and thus to a great extent obviates the tendency of the raft to hang.

Section IX.—SINGLE SPAN BRIDGES.

1. Simple beams are those used to withstand stresses merely by the strength of the material employed. Besides single timbers, iron or steel bars, rails and standard beams (Pls. IXa. and IXb., Part IIIa.) they include fished beams and composite beams (Sec. IV., para. **41**). Composite beams are particularly useful in compression, the strength of the beam then equals the sum of the strengths of the component parts. It must be remembered when using these beams butting against transverse members Simple beams.

that the compressive strength of timber across the grain is much less than with the grain.

Trussed beams.

Trussed beams.

2. Trussed and strutted beams are those which are specially strengthened with struts and ties so as to resist cross-breaking stress by utilising the compressive or tensile strength of the materials at one or more points of support in the span. Pl. XXXIV., Fig. 1, gives an example of a trussed beam. From this it is evident that the beam and the strut are in compression, and the ties are in tension. If fitted with one strut it is known as a "king" truss; if with two (see dotted lines) as a "queen" truss.

In a strutted beam (Pl. XXXIV., Fig. 2) the stresses are reversed. The beams being continuous over one or more points of support, the stresses produced are complicated. A rough method of calculation is to take the vertical struts (or ties) as rigid points of support, and to consider the beam jointed at these intermediate supports. The position of the loads is first considered so that the maximum weight may be produced at one of the points of support, the reaction at the abutment is determined and the compression or tension in the various members is found graphically (Part IIIA., Sec. III., para. **17**) (Pl. XXXV., Figs. 2 and 5). The weights are then considered in the worst position for cross-breaking strain, and the maximum stress per square inch produced by the bending moment is added to the compressive or tensile stress already found. The sum of these two stresses must not exceed the working stress for the timber used. The roadway may be carried directly on the beams, or transoms and roadbearers may be added. If a transom is provided above the strut of a "king" truss there is no cross-breaking strain in the beam, but in a "queen" truss that carries rolling loads there will always be a large cross-breaking strain due to the upward thrust of the unloaded strut. In the following examples the roadway is carried directly on the beams.

Examples of trussed beam.

3. Design two "king" trusses to carry infantry in fours and field guns over a 16-foot gap.

The greatest weight on the span is produced by infantry in fours.

Weight of infantry = $5 \times 16 \times 1\frac{1}{2}$	= 120 cwts.
Allow for superstructure and weight of beams	= 20 ,,
Total distributed load	= 140 ,,

(or 70 cwts. on each beam.)

This load is distributed as shown in Pl. XXXV., Fig. 1, and making the strut 3 feet long the stresses produced (Fig. 2) are:—

Tension in ties	= 50 cwts.
Compression in strut	= 35 ,,
Compression in beam	= 47 ,,

If the roadway is carried directly on the beams the maximum cross-breaking strain is produced by the gun wheels when at the centre of one of the half spans. Allow 20·5 cwts. as the dead load for one gun wheel + the equivalent concentrated weight of superstructure. Then

$$Mff = \frac{Wl}{4} = \frac{20 \cdot 5 \times 8 \times 12}{4} \text{ inch-cwts.} \quad \text{(Table D, Pt. III}\text{A.).}$$

Try a beam 8″ × 6″ in section, then

$$M_r = \frac{1}{6}rbd^2. \quad \text{(Table F, Pt. IIIA.).}$$

$$= \frac{1}{6}r \times 6 \times 8 \times 8$$

since $M_r = Mff$

$$\frac{1}{6}r \times 6 \times 8 \times 8 = \frac{20 \cdot 5 \times 8 \times 12}{4}$$

$$r = \frac{20 \cdot 5 \times 8 \times 12}{4 \times 8 \times 8} = 7 \cdot 7 \text{ cwts. per square inch.}$$

The compression in the beam = 47 cwts.

$$= \frac{47}{8 \times 6} \text{ or 1 cwt. per square inch.}$$

Adding the two stresses, 7·7 + 1 = 8·7 cwts. per square inch.

Taking the beam as larch and allowing a factor of safety of 5, the working stress is 8·9 cwts. per square inch, and the beam is therefore safe.

The compression in the strut is 35 cwts. A 3″ × 3″ timber 3 feet long will carry this (Part IIIA., Pl. XII.), but for convenience in fitting make the strut 6″ × 6″. Strut.

The tension in the ties is 50 cwts. Ties.

Take $1\frac{3}{4}$″ steel wire rope with safe strength

$$9\ C^2 = 27 \cdot 5 \text{ cwts.}$$

Use this double, with bearing plates round the ends of the boom and at the bottom of the strut (Pl. XXXV., Fig. 1), and tighten with a windlass. The ties should be fixed to the bottom of the struts. If chain is used for the ties, it is better not to use bearing plates, but let the links bite into the ends of the compression members; this obviates the danger of distorting any link. If single ties are used the ends of the beam should be bored in the required direction for the ties; the holes are best made by burning through the timber with a hot rod of the required diameter. Through each hole a hook is passed to which the tie is attached, a screw thread and nut being provided at the other end to allow for adjustment in length (Fig. 3). A bearing plate must be provided on the end of the beam.

Vertical bracing should be provided between the struts, and the ends of the beams must be securely fixed at the abutments. Bracing.

Queen truss. Design four "Queen" trusses to carry heavy steam tractors over a 30-ft. gap.

The roadway will be made of sleepers. The total weight of the superstructure and trussed beams may be taken as 120 cwts.

Wheel guides must be provided so that the weight of one wheel is evenly divided between two trussed beams.

The following are the dead loads for each beam (Part IIIA., Sec. III., Table B) :—

Fore wheels $\frac{100}{4} \times 2$	=	50 cwts.
Rear wheels $\frac{220}{4} \times 2$	=	110 ,,
Truck wheel $\frac{80}{4} \times 1\frac{1}{2}$	=	30 ,,
Superstructure, &c. $\frac{120}{4}$	=	30 ,,

First consider the rear axle at point C with the front axle 9 ft. from B, and determine the distribution of the loads.

$$\text{The reaction at A} = 110 \times \tfrac{20}{30} + 50 \times \tfrac{9}{30} + 15 - 5$$
$$= 103\tfrac{1}{3} - 5$$
$$= 98\tfrac{1}{3} \text{ cwts.}$$

The total load at

$$C = 110 + 10$$
$$= 120 \text{ cwts.}$$

Make the length of the struts 5 ft. and add diagonals CF, DE.

The stress diagrams (Figs. 4 and 5) then give the following result :—

Compression in the beam	=	197 cwts.
Tension AE	=	220 ,,
Tension EF	=	154 ,,
Tension ED	=	52 ,,

The maximum cross-breaking strain will occur in the beams when the rear axle is at the centre of one of the 10 ft. bays.

The load from the axle = 110 cwts. dead concentrated load.
The superstructure, &c.,

= 10 cwts. distributed load = 5 ,, ,, ,, ,,

Total ... 115 ,, ,, ,, ,,

Now

$$Mff = \frac{Wl}{4} = \frac{115 \times 10 \times 12}{4} \text{ (Part IIIA., Sec. IV., Table D).}$$

Try a beam 14″ × 12″,

$$Mr = \tfrac{1}{6}rbd^2.$$
$$= \tfrac{1}{6}r \times 12 \times 14 \times 14.$$
$$Mff = Mr.$$

$$\text{Therefore } \tfrac{1}{6} \times r \times 12 \times 14 \times 14 = \frac{115 \times 10 \times 12}{4}$$

$$r = 8{\cdot}8 \text{ cwts. per square inch.}$$

The total compression in the beams is 197 cwts., which with a 14″ × 12″ beam $= \dfrac{197}{12 \times 14}$ or 1·2 cwts. per square inch.

Add these two stresses together, the total stress is therefore equal to 10 cwts. per square inch.

The working stress of a fir beam with a factor of safety of 5 is 10·7 cwts. per square inch.

The ties carry 220 cwts. = 11 tons. **Ties.**

2″ steel bars will carry this. (Pl. XVII., Part IIIA.)

6″ × 6″ timber will be safe for the struts, but for simplicity of construction make these 12″ × 12″. **Struts.**

Bearing plates and bracing must be provided as before.

The diagonal braces CF, DE when provided are liable to work loose. With the above calculations the strength of the continuous beam is sufficient to prevent distortion, and they may therefore be omitted. **Diagonal bracing.**

The details of a trussed rail bearer with diagonal braces are given in Pl. LXVIII., Figs. 2 and 3.

Girders and girder erection.

4. Girder bridges are nearly all developments of trussed or strutted beams. They are very stiff and do not require any large timbers for their construction. They have also the great advantage that they can be made under cover and the time taken at the bridge site either for launching the girders or for fitting the superstructure is very much less than for any other type of bridge. **Girders.**

5. A variation of the strutted beam is the "Tarron" *girder. This consists of several strut members jointed together. Each joint being connected by ties with the centre of the boom for spans up to 30 feet or to two or more points on the boom for larger spans. (Pl. XXXV., Figs. 6.) Cross bracing is required between the two girders to prevent buckling sideways and wind ties should also be provided. Temporary struts are necessary to give vertical rigidity when launching, or certain members (BO, CM, DM, EN, Fig. 6) may be permanently replaced by timbers which will act as struts or ties. **Tarron girder.**

6. Girders with parallel booms may be supported on the top boom or on the bottom boom and the roadway may be carried either on the top boom or bottom boom. With heavy concentrated loads they should be supported on the bottom boom and carry the roadway on the top boom. **Girders with parallel booms.**

Such girders are of various types. A "fink" truss is a multiplication of king trusses. (Pl. XXXIV., Fig. 3.) A "Warren" girder is divided by its bracing into a series of equilateral triangles **Types.**

* A French design.

(Fig. 4). A lattice girder (Fig. 5) is virtually a combination of two "Warren" girders, and by pinning the diagonals at their intersection it may be made stiffer than a "Warren." A further combination of two lattice girders gives a double lattice. Still further additions produce a continuous web or "plate" girder. Another much used type is the "N" girder (Figs. 6 and 7).

General rules.

In these girders the top boom is in compression and the lower boom in tension. With distributed loads all bracing bars sloping upwards to the centre are struts, all sloping downwards to the centre are ties. . Vertical bars are struts when the sloping bars are ties and *vice versâ.* To allow for reversal of stresses in the bracing due to rolling loads, in "Warren" and lattice girders all the braces should be designed to act as struts or ties, and in "N" girders at least one-third the total number of panels should be double braced, the double braced panels being those at the centre.

Span and depth.

These girders may be used for spans up to 100 feet. For stiffness the depth should be at least $\frac{1}{14}$th of the span, and 7 feet is the maximum depth that can be handled readily in the field.

Design and construction.

7. For rapid construction at the bridge site, girders should be completed with cross bracing and transoms before launching. To facilitate handling, they should not be designed for infantry in fours except for short spans. Where larger spans have to be crossed, two or more bridges for infantry in file or cavalry in single file, may be constructed near the same site, heavy concentrated loads being taken across singly. Where rapidity is not essential heavier girders may be launched one at a time or several girders may be used over one span and these may be launched singly or in pairs. For rapid construction of the roadway the girders should be spaced 2 feet wider than the road. Each complete bay may then be carried on to the bridge by four to eight men who hold lashings underneath it and walk along the booms. The whole roadway for a 90-foot or 100-foot span should not then take more than from 10 to 15 minutes to construct (exclusive of the time taken for putting the bays together under cover), if plenty of men are available. For very heavy concentrated loads, girders should be placed directly under the wheels.

Members and joints.

The top boom should be approximately square in section, the bottom boom should be deep to prevent its being crushed by handspikes during launching. All members may be made laminated; by this means risk of failure through concealed knots is minimized.

i. *Compression members.*—If this boom is solid, the alignment is best maintained at the joints by using dowels (Pl. XXXVI., Fig. 3), and short cover plates nailed across the joints. The dowels should be of hard wood and should be fitted into axial holes bored in the ends of the boom at each joint. The length of any dowel should be slightly less than the sum of the lengths of the two holes into which it is to fit. Camber may be given by inserting hard wood wedges at the joints. If laminated the joints are made with trenails or bolts and nuts (Part IIIA., Sec. IV., para. **42**). Bolts are easier to fix than trenails. It is important that the planks which are most highly stressed should be placed in the centre at the panel points so that the trenail or bolt at the joint may offer double shear resistance. All laminated members should be braced together at intervals by blocks.

ii. *Tension members.*—For the boom, if of solid section, the joints are provided with cover plates. The stress is transferred across the joints (*a*) by a wire sling of the requisite number of returns passed through transverse auger holes 18 inches from the joint or preferably through several auger holes between 1 foot and 3 feet from the joint on each side; (*b*) by nails or spikes driven through each cover plate into the boom; (*c*) by bolts and nuts (Part IIIA., Sec. IV., paras. **42** to **47**). If laminated the planks must be arranged to break joint. The bracing ties, if made of iron rods, may be passed through auger holes and be fitted with nuts and bearing plates; if of wire, they may be passed through the joint augur holes (*a*), but a wire binding must then be provided round the joint, and considerable initial camber should be given to allow for the wires stretching.

Calculations

The top and bottom booms must be calculated for the maximum compression and tension respectively by using the formula, moment of resistance for each boom = rAd, when r = the safe resistance per square inch, A = the sectional area in inches, and d = the depth of the girder, measured from centre to centre of the booms. This must equal the M*f*, which will be maximum at the centre.

The stress in the web will be maximum at the abutments. For braced girders the stress in each member may be determined. For plate girders the web is calculated to resist the shear.

Example of braced girder.

Construct 2 "N" girders for a 40-ft. span to carry infantry in fours, and 18-pr. field guns—

Depth of girders to be 5 ft., and width of panels 5 ft.

Allowing 9 cwts. per foot run for total equivalent dead load—

$$W = 9 \times 40 = 360 \text{ cwts. for both girders.}$$

$$= 180 \text{ cwts. for one girder.}$$

$$\text{The } Mff = \frac{Wl}{8} = \frac{180 \times 40 \times 12}{8} \text{ inch-cwts.,}$$

and equating this to rAd,

$$rA = \frac{180 \times 40 \times 12}{8 \times 5 \times 12} = 180 \text{ cwts.}$$

If "c" denote compression and "t" denote tension—
take r_c = 10 cwts. per square inch safe stress
and r_t = 8 cwts. " "

i. *Compression boom*—

Try spars of 7″ diameter. Sectional area

$$= \frac{22}{7} \times \frac{7}{2} \times \frac{7}{2} = 38\tfrac{1}{2} \text{ square inches.}$$

The unsupported length is 5 feet, $\therefore L = \frac{5 \times 12}{7} d = 8\tfrac{4}{7}d$,

and the safe stress $= \frac{5}{6} r_c = 8\tfrac{1}{3}$ cwts. per square inch (Part IIIA., Sec. IV., para. **4**). A_c, the sectional area required,

$$= 180 \times \frac{3}{25} = 21{\cdot}6 \text{ square inches,}$$

∴ 7-inch diameter spars will be suitable, allowing sufficient margin for auger holes.

ii. *Tension boom*—

$$A_t = \frac{W}{r_t} = \frac{180}{8} = 22{\cdot}5 \text{ square inches.}$$

Use 7-inch diameter spars for this also.

iii. *Web*—

Considering the end bracing:—the reaction at the abutment $= \frac{W}{2} = 90$ cwts., but a pair of gun wheels may be close to one abutment and the rest of the bridge be crowded with infantry. Each gun wheel carries 14 cwts. and allowing 50 per cent. for live load add 21 cwts. to the reaction making a total = 111 cwts.

Draw a diagram for the forces meeting at the abutment A (Pl. XXXVI., Figs. 5 and 6), viz., the re-action, the stress in the end bracing strut and that in the end of the tension boom. From the diagram the end bracing strut carries 148 cwts. The length of this strut is 6′ 6″ = 78 ins. Try a spar 6″ diameter $l = \frac{78}{6}d = 13d$.
∴ safe $r = \frac{1}{2}r_c = 5$ cwts. per square inch (Part IIIA., Sec. IV., para. **4**).

$$A_c = \frac{148}{5} = 29\tfrac{3}{5} \text{ square inches and the sectional area}$$

$$= \frac{22}{7} \times 3 \times 3 = 28\tfrac{2}{7} \text{ square inches.}$$

A selected 6″ spar will be suitable.

From this diagram the tension at the end of the lower boom is 98 cwts. only instead of 180 cwts., as was found for the tension at the centre. The compression in the upper boom is similarly reduced at the abutment.

Vertical rods.—With an evenly distributed load the tension in the centre rod = 0. The resistance at the abutment was found to be 111 cwts. and the tension in the rods will vary evenly along the girder, so the outside tie rods may be considered to carry 111 − $27\frac{3}{4}$ = $83\frac{1}{4}$ cwts., the next ones carry $55\frac{1}{2}$ cwts., and those either side of the centre rod carry $27\frac{3}{4}$ cwts. Wrought iron bars carry 110 cwts. safe tension per square inch (Part IIIA., Sec. III., Table H). Make the two outer bars each end 1″ diameter and the three central rods of each girder $\frac{3}{4}$″ diameter. This will allow for any arrangements of the loads.

Considering the two centre struts of the bracing:—With a field gun at the centre these struts will not carry more than 20 cwts. each, but for simplicity of construction make all the bracing struts 6″ diameter and use the best pieces for the ends.

Horizontal bracing must be provided between the two top booms and also between the bottom booms either by ties or light struts arranged latticewise. Vertical bracing may be given by fixing light spars across the bottom booms directly below the transoms and lashing light struts between these and the transoms (Pl. XXXVI., Fig. 7). **Wind bracing.**

9. Plate girders are most suitable when planking and nails are available. The web for each girder then consists of stiffeners placed between the booms at intervals equal to the depth of the girder and planking nailed to the booms and stiffeners on both sides, each set of planks being inclined at an angle of 45° and in opposite directions. The shear is maximum at the abutments and here the planks are nailed touching, towards the centre they are opened out. Such girders are simple to construct and alternate planks may be omitted till after launching if it is desired to save weight. **Plate girders.**

10. Design a plate girder for 50 feet span to carry cavalry in single file and field guns passed across singly. **Example.**

Allow 4 cwts. per foot run as equivalent dead load.

$$\text{Then } W = 200 \text{ cwts. for both girders.}$$
$$= 100 \text{ cwts. for one girder.}$$

Make the depth 6 feet,

$$\text{then, as above, } rA = \frac{Wl}{8d} = \frac{100 \times 50}{8 \times 6} = 104 \text{ cwts.}$$ **Booms.**

Allow r_c = 10 cwts. and r_t = 8 cwts. (Part IIIA., Sec. III., Table F, Eastern fir.)

Then A_c = $10\frac{1}{2}$ square inches and A_t = 13 square inches.

Make the compression boom 4″ × 4″ and the tension boom 8″ × 2″ with 1″ cover plates on each side throughout. This allows a safe margin against possible buckling in the compression boom and weakness caused by nail holes in the tension boom.

Make the stiffeners 4″ × 4″ and space them 6′ 3″ apart with 6″ × 6″ transoms directly above them. **Stiffeners and transoms.**

Web. The shear at the abutments $= \frac{1}{2}$ W $= 50$ cwts., add 20 cwts. to allow for a gun being close to one abutment when the rest of the bridge is crowded with cavalry, making a total of 70 cwts. The depth of the girder is 6 feet, the vertical shear therefore equals $\frac{70}{6} = 11\frac{2}{3}$ cwts. per foot run, and this equals the horizontal shear. Planking $\frac{1}{2}$ inch thick is easily strong enough to carry this, so that the question of holding power of nails need only be considered provided that it is stiffened by being nailed to intermediate blocks. Each set of planking carries half the total shear, *i.e.*, $5\frac{5}{6}$ cwts. per foot run and four $2\frac{1}{2}$-inch cut nails per foot run used through $\frac{1}{2}$-inch planks will safely carry this. Use $6'' \times \frac{1}{2}''$ planks with three nails in each plank, top and bottom. (Pl. XXXVI., Fig. 1). Taking the bridge half loaded with cavalry and a gun at the centre, the shear near the centre

$$= \text{approx. } \frac{1}{8} W + 10 = 22\tfrac{1}{2} \text{ cwts.}$$

These planks may therefore be opened out to 3 feet interval at the centre. (Pl. XXXVI, Fig. 2.) Blocks $6'' \times 6'' \times 4''$ should be provided between the two sets of planks at points where they cross and require extra stiffening.

Wind bracing. Horizontal wind bracing may be provided by $6'' \times \frac{1}{2}''$ planks nailed diagonally from top boom to top boom between the transoms and also along the lower booms. Vertical bracing will be similarly provided between the stiffeners. (Pl. XXXVI, Fig. 4.)

11. A "Warren" girder of similar dimensions for the same purpose might be constructed with $6'' \times 1''$ deal planks. The top and bottom booms would be four planks each made up in 14 feet lengths (*i.e.*, twice the length of each panel), two out of the four planks would be jointed at the centre of each panel and cover plates be provided. The two outer triangles of web bracing would be four planks each and the remainder two planks each. Blocks for all compression members would be placed at 2 feet 4 inch intervals and the top boom might be given a width of 18 inches at the centre. $1\frac{3}{8}$-inch oak trenails or 1-inch iron bolts and nuts might be used at the panel points. If bolts are used the bearing stress on the planks need only be considered and the maximum for this would be 1,900 lbs. per square inch, which gives a factor of safety of three. If trenails are used the shearing stress on each trenail must be considered. This would not be more than 900 lbs. per square inch if the most highly stressed planks are placed in the centre of the joints and that is safe for oak.

Methods of launching. **12.** Girders may be launched by using:—

i. A single derrick on the far bank.
ii. Two derricks, one on each bank.
iii. A single derrick on the near bank.
iv. Cables stretched across the gap.
v. A single derrick in the gap.

Sheers or frames may be substituted for derricks in each case Side guys should be provided during launching to prevent tilting sideways. Preventer ropes or tackles are required to check the girder when it is nearly across the gap. Strong back struts must be provided for the derrick on the far bank as well as ties. In all cases the girders should be kept as horizontal as possible during the process. In every case except (iii) the girder is brought up or constructed at right angles to the bank.

In cases (i) and (ii) the girders are placed on rollers and the tackles either made fast to the front end of the girders or to a point slightly forward of the centre of gravity. If the former, ropes must be made fast to the back end of the girders to prevent it tipping upwards, if the latter hand spikes may be used to ease the girders forward as soon as a lift is taken on the tackles. In case (iii) the girders are placed parallel to the gap with a stout derrick at one end. The tackle is arranged to lift the girders clear off the ground, when they may be rotated with the near end bearing against the derrick. This method has been found useful with the Tarron girder. Case (iv) is very suitable for heavy girders and does not require a derrick more than 12 feet high. Two cables are stretched across the gap. Ways are picketed down on the near bank just in rear of the abutment and the girders are placed on rollers working on these ways. Long rollers with lashings attached to them should be used. The interval between the cables should be at least one and a half times the width between the girders. Two main tackles, one for each girder, are made fast to a stout pole lashed to the front end of the girders. A horizontal pull is first given but a frame should he provided on the far bank so that in the later stages a lift may be given as well (Pl. XXXVII., Fig. 1).

The bank must be bevelled off in front of the ways to allow the girders to come down on to the cables. Arrangements must also he made to lower the back end of the girders gently on to the cables as it leaves the near bank. If the end ways laid down next to the gap are cross-braced they may be pushed forward and used as a lever to assist in this operation, a small trestle or crib placed on the cables near the abutment will break the fall. During launching special note must be taken that the correct line is maintained and that the girders do not tilt sideways. If one cable stretches and causes tilt the other should at once be slacked the same amount. Men should be distributed along the length of the girders with handspikes (12 feet hard-wood levers are best) and other men must he told off for adjusting rollers. A 90-foot girder should be launched in from two to four hours. A derrick might be used instead of a frame and one main tackle only, but the rate of launching would be slower. Case (v) is sometimes possible, the tackle is made fast as in case (i) and the girder pulled out till it reaches the derrick. The derrick is then swung towards the far bank and the end of the girder lowered on to its abutment.

Carrying girders.

13. Girders may be carried by men holding stout poles placed under the lower flange. These poles must be spaced at such intervals and be of sufficient length to accommodate the total number of men required. For a pair of girders 90 feet long, 150 men might be employed, this includes parties holding side guys to prevent the girders tipping sideways. The rate of progress would average about 8 feet a minute allowing for halts.

Use of roof trusses.

14. In repairs to bridges it will often be found necessary to cross the gap in a single span and for this roof trusses may be used to act as girders, the materials stripped from the roof forming the roadway.

Strength of trusses.

In calculating the strength of trusses the following standard loads may be taken:—

	Lbs. per square foot.
Light roof covering and boarding	6
Rafters, purlins, and trusses	4
Workmen or wind	20
Total	30

This load is for roof surface measured on the slant and if measured in plan it may be taken as 32 lbs. per square foot. The spacing of trusses in most roofs varies from 8 feet to 12 feet, and taking 8 feet as a standard, the load per foot run of span $= 32 \times 8 = 256$ lbs.

Now infantry in fours $= 560 \times \frac{3}{2} = 840$ lbs. per foot run dead load,

add for superstructure 180 ,, ,, ,, ,, ,, ,,

Total ... ... 1,020 ,, ,, ,, ,, ,, ,,

and four trusses carry $4 \times 256 = 1{,}024$,, ,, ,, ,, ,, ,,

General rule.

A general rule can be given, therefore, that four trusses carry infantry in fours.

For timber trusses the roadway may be carried:—

(1) Directly on the ends of the purlins (Pl. XXXVII., Fig. 2).
(2) On slings suspended from the purlin points and ridge.
(3) Directly on the tie beams either by using a central transom and road bearers or, if the tie beam will carry the cross-breaking strain, by a series of transoms and longitudinal boarding. This method is, however, uneconomical. Six trusses are required for infantry in fours, and special precautions are required to prevent the principal rafters buckling.
(4) On end trusses used as cantilevers supporting other trusses for the central span (Pl. XXXVII., Fig. 3). Double the number of trusses are required for the cantilever

portion and should the king post be an iron rod special wood struts must be provided; precautions against buckling are also necessary as in 3.

15. Steel trusses have the advantages that they will be more likely to give sufficient span, and they are, as a rule, found in single-storey buildings and without a ceiling covering, which assists in selection and dismantling. They are also made up in 20-foot lengths for convenience in transport and can be unbolted and refitted at the bridge site.

Cantilevers.

16. Cantilever bridges have the great advantage that they require no skilled labour and few tools to construct, they are, however, wasteful of material. Cantilevers.

The first consideration is to firmly fix the inshore ends of the timbers; this may be done either by a counterbalance of stones or such material as is available or by providing anchorages. Anchorage.

17. Consider a cantilever of three layers of logs using earth and short lengths of rail as the counterbalance (Pl. XXXVII., Fig. 4). The logs should be laid butts out so as to obtain the maximum section at the points of greatest stress. The bottom layer of logs should be covered with planks so that the whole weight of the earth may take effect. Ties are provided from the inshore ends of the bottom logs and passed round the upper layers of logs as they are placed in position. The distance pieces at the outer ends of lower layers should be made of squared timbers or be built up with planks, this will keep the upper layers level. The layers should be tied together at intervals throughout their length. Cross-bracing nailed from layer to layer adds very greatly to the stiffness. Example.

To find the size and number of logs required the structure may either be considered as a girder, when the layers are well braced together, or each layer may be calculated separately and the effect of the cross bracing be disregarded. Calculations.

The rough formula $W = \frac{1}{4} \times \frac{6}{10} \times \frac{d^3}{L} \times k$ (Part IIIA., Sec. IV., para. 9) may be used as follows:—

Suppose w = the weight per foot run, live load, in cwts., and b, c, d are the lengths of the cantilevers in each layer (Pl. XXXVII., Fig. 4), then for the

top layer $W = w \times (a+b)$ and $L = b$,
middle layer $W = w \times (a+b+c)$ and $L = c$,
bottom layer $W = w \times (a+b+c+d)$ and $L = d$.

For the anchorage, if W_e = the weight of earth, and W_r = the weight of the rails,

$$\text{then } \left(W_r + \frac{W_e}{2}\right) f = w \times (a+b+c+d) \times \frac{b+c+d}{2}.$$

Section X.—TRESTLE BRIDGES AND PILE-DRIVING.

General principles.

1. In the previous Section bridges were described which required no intermediate support from the ground between the banks. The length of these bridges is limited, and intermediate supports will often be required. Between these intermediate supports the roadway will be carried by simple beams, trussed beams or girders. The supports may be made of an infinite variety of materials—*e.g.*, brushwood cylinders filled with stones, carts, stone piers, &c.; but the material most likely to be available is timber. This may be used in three principal ways:—

i. By making frames of timber which rest in a vertical position on the bed of the stream—*i.e.*, trestles.
ii. By driving timbers into the bed of the stream—*i.e.*, piles.
iii. By building up layers of timber horizontally—*i.e.*, crib piers. (Pl. XXXVIII., Figs. 4, 5, 6 and 7, and Pl. LXIX.)

2. The first form of support is the one most generally useful, and a bridge so formed is usually termed a *trestle* bridge. The requirements of a trestle, beyond the fact that it must be strong enough all over to bear the load to be brought upon it, are:—

i. It should be capable of being put in position easily.
ii. It must not be liable to collapse sideways (out of the line of the bridge).
iii. It must not be liable to fall down in the line of the bridge.
iv. It must not sink in the bed of the stream.
v. It is sometimes desirable that the member of the trestle forming its top, termed the transom, should be capable of being raised or lowered to allow for settlement of the whole frame or the adjustment of the roadway.

Of the above, (ii) is usually met by splaying outwards the feet of the outside legs and by giving diagonal bracing; (iii) is provided for by securing firmly the ends of the roadway, so that it cannot move longitudinally and throw the trestles out of the vertical. The further precaution of giving longitudinal bracing should never be omitted; (iv) only occurs when the bed is soft. It is met by placing horizontal timbers at or near the feet of the legs, or by furnishing them with flat shoes in order to spread the weight. Shoes about 15 inches square, of 1 or 1½-inch sheeting spiked to the feet of the legs of a trestle, should limit its settlement to about 12 inches in any mud under ordinary loads. A wood fillet of about 1 by 1½-inch should be nailed round the edges of the undersides of the shoes.

3. It is assumed that the section of the gap has been taken—that is, that the positions of the trestles have been fixed, and that at each position the vertical height has been ascertained from the bottom of the gap to a line joining the banks. Before commencing the construction of the trestles, it is necessary in many cases to make certain additions to this measured height. These additions are :— Construction of trestles.

i. An allowance for a soft bed, if it exists. This is done as already stated (para. 2), by affixing shoes to the feet of the trestles and allowing that, in very soft mud, the trestles will not sink more than about 12 inches. Or a horizontal member may form part of the trestle and be placed at or near the bottom of the legs. This increases the bearing surface on the soft bed and in ordinary cases the trestle should not sink further than the middle of this member, which is termed a ledger. (On rocky ground, on the contrary, if there is a ledger it should not be placed near the bottom of the legs.)

ii. *Camber.*—The amount to be allowed for each trestle will depend upon its position in bridge with reference to the ends of the bridge.

iii. If the legs of the trestle are not vertical but are splayed outwards towards the feet, an allowance must be made for this fact in measuring the length along the leg from the butt to the transom. This allowance will depend upon the angle of the legs and can be readily calculated. For the trestle shown on Pl. XLII., Fig. 1, it amounts to 1 inch in 6 feet, while for the four-legged trestle shown in Fig. 2, the amount is 3 inches in 6 feet. In marking the legs of a trestle preparatory to construction, care must be taken to make the necessary allowance for the thickness of the roadway.

In preparing for the construction of the trestles for a bridge it is not necessary to lay out on the ground the section of the gap, the timbers can be marked from the measurements taken and the allowances to be made.

Framed trestles.

4. The variety of trestles that may be made is very great, and the exact pattern to be chosen in any case will depend upon the timber and fastenings available. The best are those which are framed together with the transom resting on the head of the legs. Examples are shown on Pls. XXXIX. and XL., which also show other methods of fastening the transom to the legs. Most of these require some form of iron fastening or Framed trestles.

wooden dowels. The iron fastenings most commonly employed are dogs, drift-bolts, bolts and nuts, spikes, nails, fishplates and hoop iron. The size of the timbers to be used will depend upon the loads to be carried.

Framed trestles may also be made in a manner similar to railway trestles, as described in Sec. XIII. These would generally be employed for very heavy traffic only. For economy of material, the width of a bridge built for such traffic should be restricted to that actually required for its passage. By doing this the road-bearers can be placed directly below the wheels, as in the case of railway bridges. In order to keep the wheels in their proper track stout wheel guides must be provided. These should be about 6 inches by 6 inches in section. For ordinary mechanical transport it will be sufficient to place the wheel guides from 9 to 12 inches further apart than the extreme wheel track of the vehicles. The roadway should be of planking at least 3 inches thick.

Pl. XLI., Fig. 1, shows a trestle of squared timber for a bridge designed to carry British service mechanical transport, with a second roadway for ordinary field loads. The road-bearers, &c., are calculated for a bay of 16 feet. In a double bridge of this nature careful arrangements must be made to prevent the heavy traffic using the wrong side of the bridge. Any danger from this will be avoided by providing two tracks, each capable of carrying all kinds of vehicles, as shown in Fig. 2. The amount of material required in the second case is only slightly in excess of that necessary for the first.

If economy of large timbers has to be studied, the roadway for ordinary traffic shown in Fig. 1 may be borne by separate trestles of a lighter description. In certain cases it may be advantageous to have a completely separate bridge for ordinary traffic.

In all bridges of the type shown for heavy traffic, the shore ends should be splayed to a width of about 10 feet, in order to allow easy access for the vehicles on to the bridge.

Sometimes it may be desirable to put trestles in a bridge which have inherent stability. Such a trestle is shown on Pl. XL., Fig. 3.

Lashed Trestles.

Lashed trestles.

5. In places where it is impossible to obtain the necessary fastenings for framed trestles, lashings of wire or rope may sometimes be available. These have the disadvantage of applying the load eccentrically to the legs, and in the case of hemp ropes there is the additional drawback that the lashings will not remain taut for any length of time. They need constant attention and frequent renewal.

Types of lashed trestles (two-legged and four-legged) are given on Pl. XLII., Figs. 1 and 2.

6. The method of constructing the usual form of a lashed spar trestle is as follows :—

Construction of lashed trestle.

Each spar, except the diagonals, must first be marked at the places where the other spars will cross it. Spars are generally marked with a ring of chalk round the place where the *edge* of the crossing spar will come, and a diagonal cross on the part which will be hidden by the crossing spar. The *edge* is to be taken to mean the inside lines of the legs, as seen in elevation, or the top of the transom, or the bottom of the ledger, as in Pl. XLII., Fig. 3.

When marking the transom and ledger, their centre points should first be marked with a ring, and the other marks put at equal distances from it. The distance apart of the marks on the transom should be 18 inches greater than the clear width of roadway required.

The legs slope outwards at 6/1, so the distance apart of the marks on the ledger can be calculated, by adding to the distance marked on the transom one-third of the height from transom to ledger.

The transom and ledger are then laid out with the legs on top of them, so that the marks cover each other, and they are then lashed together with square lashings.

The butts of the diagonals are also lashed with the square lashing; both tips and one butt should be on the opposite side of the legs to the transom, the other butt being on the same side. The tips are kept well below their final position while the butts are being lashed, so that when the tips are brought up to their final position the lashing at the butts will be tautened.

Two men must work at each lashing in order to get it taut.

The trestle is next *squared* by measuring from the centre of each transom lashing diagonally to the centre of the opposite ledger lashing, and making these two measurements equal by forcing the butts sideways, without allowing the transom to move.

When square, the tips of the diagonals are lashed to the legs with square lashings, and the diagonals themselves are lashed together where they cross with a diagonal lashing. The lashings of the diagonals must be done carefully or the bridge will be liable to collapse sideways.

Placing trestles.

7. There are many ways of placing trestles. The most usual methods are :—

Carrying

(1) Carrying the trestle into position and up-ending it. This can only be done with light trestles in a dry gap or where the water is very shallow. Where these conditions hold it is the quickest way.

Launching by ways.

(2) Launching the trestle from the head of the bridge. (Pl. XLII., Fig. 4.) This method is hardly possible in a rapid stream. Two baulks are placed as ways from the transom of the trestle last in bridge and made to project into the stream a little further than the place where the feet of the next trestle are to be. The ends of these ways must be weighted to keep them down. The trestle is now carried on to the bridge, feet foremost; the feet are weighted, if necessary, to prevent them from floating; two foot-ropes are secured to the feet, below the ledgers (if any) by long loops formed by a single bowline, and a couple of light poles, D, longer than the bay, are loosely lashed to the top of the trestle. This is now lowered down the inclined ways, and two road-bearers which have been previously marked with chalk at the points where they will eventually rest upon the transoms are brought up and fixed roughly in position on the transom. The head is then shoved out by the poles, D, until the inner chalk marks come over the transom at the head of the bridge, to which they are then fixed. The ways are then removed, and the trestle is brought upright by means of the foot-ropes and the poles, D, and rowed to the right or left by means of a spar placed under the transom from the head of the bridge. If it is found unsteady or not level in its new position, it must be hauled back, and the ledger or transom adjusted.

At least two foot-ropes (not less than 2 inches) are required in every case. Two guys and two poles, D, are required for each two or four-legged trestle, but if the gap is small the two poles may be replaced by other guys passed to the opposite bank. It is also convenient in that case to have two additional foot-ropes passed to the opposite bank.

Floating and distance frame.

(3) Floating the trestle out to the head of the bridge and raising it by means of a distance frame. (Pl. XLIII.) This method is especially suited for very heavy trestles and deep water, but is difficult of application in a very rapid stream. A distance frame is made of four spars with diagonals of rope and floated to the head of the bridge, as shown in Figs. 1 and 2. The trestle is then floated and towed or warped out to the bridgehead, and placed as shown in Fig. 4, the tips pointing away from the bridgehead, and the bottom of the legs floating underneath the front of the distance frame. Head guys are attached and two sets of foot-ropes, one of which is brought up round the front spar of the frame on to the bridge. The trestle is then raised (Fig. 3)

by hauling in the head guys and easing off the ordinary foot-ropes, the legs pivoting about the front spar of the distance frame. As the trestle becomes vertical, the extra set of foot-ropes is eased off and the legs take the bottom. No weighting of the feet is necessary. The distance frame ensures accurate position, the extra foot-ropes preventing it from rising when the head guys are hauled on.

Another form of this method is shown on Pl. XLIV., Fig. 1, where the second set of foot-ropes is done away with and its place taken by a handrail fixed to the head of the trestle before raising.

(4) Floating the trestle out to the head of the bridge and raising it by means of distance baulks, which are afterwards left as longitudinal braces. (Pl. XLIV., Fig. 2.)

The trestle is floated to AC, and a light frame AB of two spars diagonally braced is then fixed at A and B. Rope DE is then hauled on and the trestle is brought into a vertical position at A′C′. The frame AB remains as longitudinal bracing A′B. The distance A′B must be obtained from the section of the gap.

(5) Placing the trestle horizontally on a raft which is then moved to the head of the bridge and the trestle up-ended. The feet must point towards the bridgehead and must project beyond the edge of the raft. Handrails, lengthened with guys, must be fastened to the head of the trestle at each side and the ends of the guys passed on to the bridgehead. Foot-ropes are also required; these remain at first on the raft. By these means the trestle can be up-ended and manœuvred into its correct position. The raft must be kept stationary during the process. **Placing from a raft.**

(6) Placing the trestle in a vertical position between two boats or rafts, floating it to its place and then lowering it to take the ground.

(7) Placing the trestle by means of a swinging derrick on a raft.

(8) Placing the trestle by means of a carriage or improvised crane on the bridge. An example of this is shown on Pl. XLI., Fig. 3. **Placing by carriage.**

This method can be employed in very rapid streams. It is necessary to remove the carriage from the bridge when a trestle has been placed in order to make room for the next trestle to be carried to the bridgehead. This must be done feet foremost. Before picking up the trestle with the carriage the two outside road-bearers must be lashed to the transom. In rapid streams the trestle must be lowered very quickly into the water. In slow streams trestles may be floated to the bridgehead and picked up by the projecting beam of the carriage. In this case the carriage remains at the head of the bridge.

A variation of this method is to use rollers in place of the carriage, as shown on Pl. XLIV., Fig. 3. Here it must be remembered that the trestle will move forward twice as rapidly as the rollers.

Piles and pile driving.

8. The use of piles becomes necessary when the ground is of such a nature that it will not support the required weight, even though this weight has been spread over as great an area as possible, or where the ground is soft and either constantly or occasionally covered with water, and where there is in consequence a danger of scouring and undermining. Piles are also used instead of trestles in cases where the structure is to be of a more or less permanent nature, and is at the same time subject to lateral shocks, such as, for instance, would be the case with a jetty or landing stage at the base of operations of an army.

Ferro-concrete being beyond the scope of this book, piles may be described as round or rectangular baulks of timber of a length suitable to the work in hand, which are driven into the ground by one of the methods to be described later, and on which the contemplated structure is erected.

The timber from which it is proposed to make a pile should be selected on account of its soundness, straightness of grain, and freedom from shakes and large or decayed knots. Large knots, particularly if they run diagonally across the pile, are a source of danger, for the pile is very likely to fail at these points in the process of being driven.

Any timber available may be used for piles provided it is not brittle. Hard wood piles drive best, as with them there is less spring and less brooming at the pile head.

Piles are prepared from the log by removing all bark and large projections and by cutting the larger end square, while the smaller end is brought to a blunt point. Many authorities prefer that piles should be hewed into shape. Piles so formed are said to last longer than when sawn. Long finely tapered points are not satisfactory; it is found that such are liable to break or to be badly bent if any hard object is met with while the pile is being driven. The planes forming the point should make an angle of about 30 degrees with the axis of the pile.

It is important that the head of the pile (as that part which receives the blows of the monkey is called) should be cut truly square with the axis of the log. If this is not done the blows of the monkey are received on one edge and not over the entire section and, apart from consequent difficulty in guiding it, the pile is likely to be split.

In structures such as bridges or jetties piles are usually driven in clusters, technically termed *bents*. The nature and amount of traffic governs the number and arrangement of the piles in a bent. For ordinary railway traffic where the bents do not exceed 5 feet in height three vertical piles are usually sufficient. These are arranged, one on the centre line and one on either side some few feet away, according to gauge. If the bents are between 5 and 10 feet high, four vertical piles are usually employed for a double track. They are generally spaced so that 4 feet separate the inner pair, while the outside piles are some 11 feet apart. With bents above 10 feet in height two more piles driven to a batter are added on the outside of each bent. The batter or slope at which these outside piles are driven varies from 1 inch to 3 inches per foot of height.

9. If the pile is to be driven through a hard stratum it will be necessary to protect the point with an iron shoe, but in soft silt a square-ended pile often drives more truly. This is owing to the fact that a square end has no tendency to glance from an obstruction such as a root, as is the case with a pointed pile, but will either shear through the obstruction or carry it down with it. Shoes.

When it is necessary to arm the pile with a shoe, the shoe should be made to fit closely to the timber of the pile, and should be fixed with bolts, great care being taken to ensure that the point of the timber transfers the blow of the driver to the shoe and that the strain is not taken by the bolts. If this precaution is not taken the bolts will either split the pile or themselves be broken, in which case the shoe will shift and fail to protect the timber. To prevent the iron point shifting some shoes are constructed with a central dowel to fit into a corresponding hole in the axis of the pile. Such an arrangement should not be necessary with careful fitting of a shoe. The most satisfactory form of shoe is that composed of a solid conical point with straps extending from its sides. The timber is brought to a blunt point, which fits squarely on to and is of the same size as the base of the iron point. The straps are bolted through the timber and are only intended to prevent the shoe from becoming displaced. In order to do this satisfactorily these straps should fit and lie closely along the planes forming the timber point. A chisel-shaped point is very frequently used in sheet piling work, and is said to give excellent results in ground in which large stones are met with. (Pl. XLV., Figs. 4 and 5.)

10. In order to prevent the head of the pile from splitting under the repeated blows of the monkey, an iron ring should be fitted round the timber. The head of the pile is chamfered for a few inches from the end, so that the ring will slip on to the timber. After two or three light blows from the driver the ring will be found to be clasping the pile firmly. A quicker but less satis- Rings.

factory method of fitting the ring is to place a band, whose diameter is from $1\frac{1}{2}$ to 2 inches less than that of the timber, on top of the pile, and with a few light blows of the monkey drive the ring into the timber. Such a ring is better than none, but the tendency of a ring so fitted is to split long layers from the sides of the pile and the method should only be adopted under stress of circumstances.

Ordinary pile head rings are made of $\frac{1}{2}$-inch iron, one at least for every pile. But if pile driving on an extensive scale is in progress, much heavier rings, which are removed and used again and again, are often economical. These rings should be at least 1 inch thick and 3 inches deep. This ring is fitted as previously described, and the pile driven to the desired depth. Before moving the pile driver the ring is removed from the head of the pile as follows :—A lever of sound timber some 4 feet long, as shown on Pl. XLVI., Fig. 1, is fitted with a metal band at A, to which is attached a claw, while the other end is fitted with an iron ring. The plain end of the lever is placed on the head of the pile and the claw is driven under the bottom edge of the ring. The monkey is detached from the chain and the chain connected to the ring B. The chain is then hauled up on the windlass, the head of the pile forming the fulcrum, and the ring is disengaged and is free to be used again.

With rings made of $\frac{1}{2}$-inch iron, even when the greatest care has heen taken in the welding, fractures often occur during driving. When this happens driving should he discontinued, the crushed end of the pile should be cut off and a new ring fitted.

Brooming.

11. As a result of the constant blows of the monkey the fibres at the head of the pile are bound to be crushed, but as long as a ring is used this "brooming" as it is called affects only the head of the pile, and if the broomed end is cut off the timber below will be found quite sound. So long as a ring is used there will be no signs of longitudinal splits, even though the pile is badly broomed. The result of the brooming of the end of a pile is to reduce the effect of the blow of the monkey, and it has often been found that a pile which has apparently ceased to drive has moved several inches when the broomed end has been removed and the blow delivered on to the sound end.

Pile anvils.

12. Pile anvils, caps or dollies are sometimes used in place of rings on the pile to reduce this brooming. The anvil consists of a hard wood block moving in guides, and is fitted with a recessed collar on the underside which receives the head of the pile, and fits it closely. The blow of the monkey is received on the anvil, thus saving the pile itself from damage. This arrangement is often desirable when soft wood piles must be driven, and it has the double advantage that the head of the pile is not only protected but guided.

Joints.

13. In situations where soft ground extends to a considerable depth, and when, in consequence, a pile has to be driven a long way to obtain the requisite bearing power, it may be necessary to join two timbers to obtain a pile of the desired length. The first pile is driven until the sound portion below the broomed head is near the ground or water. The end is then cut off and the next timber fastened to it. The joint should be as simple as possible; but whatever its form, it must be such that the blow of the monkey is transmitted evenly over the whole section of the pile. The simplest form of joint is that in which each timber is halved and the halved ends are butted together. In this case the bolts must take no part of the driving effect of the monkey. Their work consists only of holding the timbers together. The length of the joint should be some 25 per cent. greater than the breadth of the pile. Piles which have to be driven to a great depth, or which project a considerable distance above ground, are often joined by splicing. With round timbers the splice is formed by cutting the timbers to an octagonal section and spiking a baulk of suitable size on to each octagonal face, the baulks extending some 10 feet on either side of the junction of the two timbers.

Sometimes in order to keep the ends of the two portions of the pile from moving from their proper alignment, iron dowels are employed. These dowels are usually $1\frac{1}{2}$ inches in diameter and 2 feet in length, and are inserted an equal depth in each timber. Owing to the great leverage these dowels cannot be expected to support in any way the superimposed timber. Their use is only to prevent any lateral movement of the ends of the timbers.

Iron rings or collars do not make satisfactory joints between timbers for piles. They are costly, and it is difficult to make them fit.

14. The bearing power of piles is not so great when freshly driven as after a period of rest, when the ground round them has again become consolidated. And the weight on the piles is then supported partly by the upward pressure on their points and partly by the frictional resistance of their surfaces in contact with the soil. In these circumstances it is evident that the safe load on any pile cannot be actually calculated by any formula expressed in terms of the fall of the monkey or the set of the pile into the ground as the result of a particular blow. Such formulæ are useful as a guide to what a pile may be expected to bear, but it must be borne in mind that the results obtained from these formulæ should be tested by actual experiments. This may be done by driving two bents of piles similar to those which will be employed in the completed structure and on them erecting a platform. This should be loaded with the greatest weight that can possibly come on one bay of the structure when complete. If no settlement takes place the piles of other bents, if driven to a similar depth

Bearing power of piles.

and until they give a similar resistance to the last few blows, will safely carry the load required.

Rankine's rule.

15. Rankine's rule of thumb for the safe load on a pile is 1,000 lbs. per square inch of section when the pile is driven home to firm ground and 200 lbs. when it is not.

Wellington's formula.

16. Wellington's formula is a simple and reliable one for ordinary hand pile driving machines, viz. :—

$$P = \frac{2\,w\,H}{S + 1}$$

Where P = safe load in any unit.
w = weight of monkey in the same unit.
H = fall of the monkey in feet.
S = set of the pile in inches.

In this formula, H should be measured when the head of the pile is in good condition and when there is no considerable rebound after the blow.

With regard to S, the correct value can only be determined by taking the mean of the sets for a number of similar blows. The penetration should have been taking place at a fairly uniform or at a regularly decreasing rate. There should be reasonable grounds for assuming that this penetration would continue uniformly if the pile were driven several feet further. This may be ascertained by driving a test pile to a greater depth. The head of the pile must be in sound condition. Brooming, as previously stated, greatly affects the result of a blow. The penetration, too, should be at a reasonably rapid as well as at a uniform rate. It should be further remembered that very small sets (less than ¼ inch) may be due to the crushing of the timber, not necessarily above ground where it can be observed. This is particularly important in the case of soft wood piles. The weight of the monkey and the height of the fall must be taken into consideration when deciding between what may be considered an acceptable set and what is due to possible crushing at the point.

For use with a steam pile driver Wellington's formula is modified to—

$$P = \frac{2\,w\,H}{S + 0{\cdot}1}$$

Stability of piles.

17. Apart from bearing power piles should be driven to a sufficient depth to ensure stability and to be free from the effects of scouring. Should it be impossible to drive the pile as deep as is desirable for the purpose, the filling in of the space between the piles with earth or stones will add very considerably to the stability of the structure. Such a procedure would be adopted in a situation where an impenetrable stratum was met with a few feet below the surface. The vibration set up in a pile by the action of running water or by the passage of traffic, if it

extends to the point of the pile, will cause settlement. Piles must therefore be driven to such a depth that these vibrations do not reach the point. The depth requisite depends on the nature of the surrounding soil.

18. Heavy piles are most satisfactorily driven by means of a properly constructed pile driving machine, such as the pattern shown in Pl. XLV., Fig. 2. This form is too well known to require description in detail; the platform should be mounted on a turntable for the greater convenience in use. The ordinary manual pile driver is provided with a winch, by means of which the monkey is raised. Driving piles.

If this form of pile driver is not available a lighter one without a winch may be used where the work is not too heavy. This is termed a ringing engine. It consists of a frame similar to that described above. The monkey is worked by men alternately hauling and letting go at the free end of the rope or chain which is attached to the monkey and runs over a sheave at the top of the frame. At a convenient height from the ground the free end of the rope or chain terminates in an eye-splice or ring to which any number of ropes may be attached, according to the weight of the monkey and the number of men employed. A drop of 4 feet is usually allowed for with this machine. A light monkey must of necessity be used, about 300 lbs. being the largest convenient size. One man should be allowed for about each 40 lbs. weight of monkey.

If the frame and guides necessary for a ringing engine are not available, piles may be driven in the following manner:—Two guides are bolted to the pile itself and are fitted with a sheave at the top, over which the rope for raising the monkey passes. The monkey moves between the guides as in the ordinary pattern of driver. The pile is maintained in a vertical position by means of guys. Piles 35 feet long have been driven successfully by this method. (Pl. XLV., Fig. 1.)

In stiff clay, sand or gravel a heavy monkey with a correspondingly short fall gives better results than a light monkey with a long fall, although the energy of the blow may be the same. It would seem that the force of the blow of the quickly moving light monkey is largely expended in brooming the head of the pile and in causing the timber to bend.

A pile drives more easily when the blows follow one another rapidly. This is probably due to the skin friction of the pile being less developed in the short interval between blows than is the case when blows follow one another at a considerable interval of time.

In some situations piles drive easily and regularly to a certain depth and then refuse to penetrate further. This may be caused by a thin stratum of some hard material such as gravel. It may require many blows to drive through this and the pile may be injured in the process. The hard stratum may overlie soft material, and once through it the pile will again drive easily. In such a case, if the depth of soil through which the pile has been driven is sufficient to give lateral stability, or if this can be ensured by other means, it is better not to attempt to penetrate the hard stratum and driving should be stopped after a practical refusal to move after a few blows. Before deciding, however, to stop driving, it would be well to determine the nature of the underlying soil and the thickness of the hard stratum, which can be done by driving a test pile. Should it be decided to drive through the hard stratum, the introduction of a dolly of hard wood, or a pile anvil as described previously, between the monkey and the head of the pile will tend to reduce brooming.

Driving by water jet.

19. Another method of driving piles is by means of a water jet. This has the great advantage that the pile is not liable to damage by the blows of a monkey. It is a very rapid and effective method in sand, silt or clay, and even gravel. Unless a considerable head is available this cannot be regarded as a "field process."

A pipe is attached to the pile, being either fixed in a chase cut to receive it or simply fastened to the outside. The pipe ends in a nozzle at the point of the pile. Water is forced down the pipe, and as it issues from the nozzle removes or loosens the material under the point and in its vicinity. The pile thus sinks by its own weight or is assisted by attaching a weight at its head. Sometimes blows from a light monkey are added to the action of the water jet. In order that the pile may sink rapidly a very considerable volume of water is required. A rough estimate may be based on the following rule of thumb:—To depths of 40 feet, use 16 gallons per inch of average diameter per minute. At greater depths increase this at the rate of 4 gallons per inch of diameter of the pile for each additional 10 feet of penetration. When the pile is driven to within a few inches of its final depth the pump is stopped, the pipe withdrawn and a few blows of the monkey are given to bring the pile to its final resting place.

Placing driver.

20. To place a pile driver in a position for work is often a matter of some difficulty. The method usually adopted is the erection of falsework on which road-bearers may be laid. On these rails are fixed which form the track for the wheels of the pile driver. But if the ground into which the piles are to be driven slopes steeply, the falsework soon assumes unwieldy proportions, and cantilever beams for the support of the driver will have to be substituted. If a constant water level is available the simplest arrangement is to place the driver on a raft, which is anchored in position as required. In any case the piles are raised to a vertical position before driving by means of the chain or rope of the winch.

21. As soon as driving has advanced sufficiently the work of cutting the piles to level may be undertaken, ready for fitting the topsills or transoms. The following is the best method of marking piles for cutting :—The officer in charge, by means of a level, marks the correct elevation for the cut on the two outside piles in each bent. Two battens or planks, each having a straight edge and of sufficient length to reach across the whole bent, are then nailed to the piles, one on each face of the bent with their straight edges exactly at the correct elevation. Each bent is treated in a similar manner. The tops of the piles are then cut off level with the straight edge by two men using a cross-cut saw. (Pl. XLVI., Fig. 2.) Cutting to level.

22. Topsills or transoms for piles are either solid baulks or what are termed split caps. To form a split cap, two baulks are used, each of half the section of the solid baulk required. A tongue of about one-quarter the thickness and the full width of the pile is formed at the top of each pile, and one of the baulks of the split cap is placed on either side, being held in position by two bolts passed through the entire cap and the tongue. The cap baulks are not notched, but are allowed to rest on the flats formed on each pile. (Pl. XLVI., Fig. 4.) This form of cap has several advantages over the solid, but takes longer to fix. Repairs are much simplified, and may often be done without stopping the traffic. For hasty work solid topsills (or caps) will more usually be employed. They are generally fastened by means of drift-bolts, dogs, or by a mortice and tenon joint. If the latter method is adopted the tenon should not be less than 3 inches thick, and its breadth should not be much less than the breadth of the pile. In length it should not exceed half the depth of the sill. (Fig. 3.) Tenons are pinned into their mortices by trenails or bolts driven horizontally. Allowance must be made for the tenon in cutting the piles to length. Transoms.

If drift-bolts are to be used, the heads of the piles are cut off square and the topsills rest across their tops. One drift bolt per pile is sufficient. For 12-inch timbers drift-bolts should be from 20 to 24 inches long.

23. In a permanent structure a record of each pile should be kept under the following headings :— Records to be kept.

Date.
Bent No.
Pile No.
Weight of monkey.
Height of fall of last blow.
Penetration at last blow.
Depth in ground.
Length of cut-off.

Light piles and rapid pile driving.

24. Piles of light scantling may be driven without the use of an ordinary machine, and under certain circumstances are a more expeditious method of construction than trestles. This is particularly the case when soft silty beds are encountered, since piles can be driven to a firm bearing before the transom is fixed. Thus settlement and the consequent need of adjustment of the roadway may be avoided.

Such piles may be driven by men with mauls or by means of what is called a Swiss pile driver. This is an arrangement wherein each pile supports the guide for the monkey. A vertical hole a foot in depth is bored axially in the centre of the head of the pile. In this hole is temporarily placed a guide rod for the monkey, which is bored with a hole of a size which allows it to slide easily on the guide rod. This rod may be made of a 6 feet length of 1-inch bar iron while the monkey may be a block of hard wood about 3 feet long, with iron bands on either end to prevent splitting, and four handles of $\frac{3}{4}$-inch iron served with rope or spunyarn. (Pl. XLVI., Fig. 5.) If there is no time to prepare these handles, short ones projecting at right angles may be made to serve, but they are not so convenient as those described above. The monkey should not exceed 130 lbs. in weight for use by four men. The speed of driving will be increased if the platform for the men is attached to the pile.

A convenient way of placing light piles is to push out a light trestle and lay a temporary roadway to it about 18 inches below the permanent level and extending beyond the positions of the piles. These can then be placed by hand from the roadway.

25. Another way is to make two temporary gangways, one on each side of the bridge as at AB, in Pl. XLVII., Fig. 2, by means of two spars lashed one on each side of the pile head, with a cross-piece fixed at the positions of the pile to be driven C. A man can go out to the cross-piece and, by means of a foot-rope, guide the point of the pile into position. The head can be pushed out by a spar lashed to it so as to be 2 or 3 feet above the roadway when the pile is upright. The other end of this spar is lashed to the pile last driven, B, so that it can be eased out or in to keep the pile upright. This operation is to be done simultaneously on each side of the bridge. Before pushing out the piles one plank is lashed across the ends of the spars outside the piles and another just inside them. The piles are kept from setting to right or left by anchors and cables in the stream. If the cables are long the anchors need not often be shifted. Four men then go to each pile-head and drive the two piles together, standing on the two planks in order to let their weight assist.

26. Another method of driving light piles is shown on Pl. XLVII., Fig. 1. The first pier is placed as above and the road-bearers of the bay are placed and fastened to the transom supporting them. A plank is lashed across them on their underside (A, Fig. 1) and long spars are placed as cantilevers, projecting beyond the last pier fixed a distance equal to one bay plus about 2 feet 6 inches, and on these are placed planks. The piles are then carried out on to the platform thus formed and are dropped into their places between pairs of such cantilevers, which should enclose them. The piles are then mauled into position by men standing on the platform until they will stand by themselves. The cantilevers are then lashed to the piles, the plank A removed and driving continued. When driven sufficiently, the bent is capped and the road-bearers fixed. The process is then repeated.

27. A rapid method of forming a light infantry bridge is shown on Pl. XLVII., Figs. 3 and 4. The piles are of light scantling, 3 inches or 4 inches thick, and are placed in pairs with a plank, which finally forms the transom, lightly nailed to them. The piles are driven only 3 feet apart and are carried out by one man walking along a plank pushed out from the shore and kept from tipping by two other men standing on the inshore end. The roadway is kept one bay behind the last pier in bridge, as shown on the figure. As the pair of piles are driven to a bearing the transoms are adjusted as necessary and then firmly nailed.

28. Improvised pile drivers may often have to be used in the field. The following is a description of one constructed from the bridging equipment of a field company, which has been found very effective. (Pl. XLVIII.) Improvised pile drivers.

The pile driver consists of two service trestle legs, standing in half a sleeper as base, which is spiked to the platform or bridge head on which the driver works. A cross-bar is lashed to the tops of the legs to support the monkey, which is worked up and down by a pulley block lashed to the cross bars.

The monkey consists of a block of wood 200 lbs. in weight through which two holes are bored to take iron bolts 2 feet 3 inches long. These bolts work up and down between the trestle legs, which act as guides, and keep the monkey in position. The monkey is bound top and bottom by ½ inch wire bands. (Fig. 1.)

The pile driver is held erect by four guys attached to convenient holdfasts; or it may be rigged with a triangular spar base, the guys being then dispensed with. (Fig. 2.)

The Service trestle legs are placed side by side, and the head of the driver fixed up and guys attached.

The apparatus is then erected by the guys and placed in position.

Six men can erect this pile driver in half an hour. It requires four men to work it, and two reliefs are necessary; the complete detachment being 1 N.C.O. and 8 men.

Stores required.

The following stores are required :—

(a) *Carried in field company equipment.*

2 Service trestle legs.
1 2-inch block (double).
12 2-inch lashings.
4 5-foot pickets.

(b) *To be made and carried.*

2 half sleepers (halved) for legs.
2 1-inch bolts, 2 feet 3 inches long, with nuts and 8 plates.
Iron band, $\frac{1}{2}$ inch wide, $\frac{1}{4}$ inch thick, 10 feet long, for monkey.
The total weight of the above would be about 28 lbs.

(c) *Monkey.*

A piece of timber 3 feet long and 15 inches diameter—weight about 200 lbs. This would not have to be carried. It could probably be easily procured locally.

Pile driver of two rails.

The time taken to drive a pile 8″ × 8″ a depth of 5′ 6″ in a river bottom of hard gravel was $1\frac{1}{2}$ hours.

29. Pl. XLIX. shows another example of a pile driver extemporised from two rails. These form very good slides for the monkey as well as a satisfactory upright. The monkey and the catch must be specially made.

Section XI.—SUSPENSION BRIDGES AND AERIAL ROPEWAYS.

General description.

1. Suspension bridges are the most rapidly constructed and most practical type of field bridge for spans of 100 feet and upwards where the bottom of the gap to be bridged cannot be used.

As the stability of the whole bridge depends on its anchorages the site should be chosen with banks of sound rock or earth, and if possible of the same height.

Cables.

2. The best materials for cables are chains or steel wire ropes; hemp ropes, sail cloth, thongs of hide, and ropes of creepers or grass, or even small baulks pinned (Pl. LII., Fig. 6), or boards nailed (Fig. 5) together, are sometimes employed. When several ropes are used instead of one large one, care must be taken to stretch them all evenly. To secure this, hemp ropes are, when small, twisted into a cable, or they are fastened at one end alongside each other, uniformly stretched and bound up into a bundle with ties at short intervals.

Improvised wire cables may be made by one of the methods described in Part IIIA. Sec. IV., para. 30.

3. The regulation of the dip in the cable of a suspension bridge is a matter of considerable practical difficulty, as it is impossible to take all the slack out of the turns of the anchorage. This difficulty increases with the size of the cables. Differential tackles are the best means for dealing with the adjustment of cables. **Dip.**

The *dip* of the cable usually varies from $\frac{1}{10}$th to $\frac{1}{15}$th. A deep curve causes less stress in the cable, and does not require such distant anchorages; while a flat one is less liable to oscillation, but loses form more quickly from stretching.

4. The great difficulty with suspension roadway is the want of stiffness with a concentrated load; particularly near the piers. With high banks, ties may be taken down from the roadway, and anchored to the bank; these help to check oscillation, and should be used when practicable; but the main point is to use long road-bearers and long stiff ribands breaking joint with the road-bearers or better still, to use light lattice girders of planking, which answer both as road-bearers and stiffeners. Lateral oscillations, due to moving loads and wind, may be provided for by guys taken from the centre of the bridge and secured to hold-fasts on the banks of the gap, as far to the right and left of the bridge as is convenient. **Stiffeners and wind guys.**

By using two cables on either side of the bridge and combining these into girders the stiffness of a suspension bridge is greatly increased (para. 25).

Theory and formulæ.

5. The stresses in suspension bridges are calculated on the assumption that the load is uniformly distributed along a horizontal line, and that the slings are sufficiently numerous to permit the cable being viewed as a continuous curve, in which case the curve of the cable is a parabola.

In order to ensure a direct vertical thrust on the piers, the fore and back parts of the cable should make equal angles with the pier-head. When owing to the nature of the banks this cannot be done, the piers must be stayed and strutted, so as to provide fully for oblique thrust on them.

Referring to Plate LI., Fig. 6 :—

$$\text{If JK is} \left\{ \begin{matrix} \text{greater} \\ \text{less} \end{matrix} \right\} \text{than } \frac{1}{2} \text{KO, the pier will need} \left\{ \begin{matrix} \text{strutting} \\ \text{staying} \end{matrix} \right\}.$$

In practice it is better to both strut and stay.

a = the span in feet.
T = tension in all the cables together.
C = compression in all the legs of one pier.
d = dip of cable = $\frac{1}{n}$ of span.

Formulæ for whole cable.	*Formulæ for any point* P.
$d = \frac{a}{n}$.	$y = \frac{4d}{a^2} x^2$ or $\frac{4x^2}{an}$.
$\tan\theta = \frac{4d}{a}$ or $\frac{4}{n}$.	$\tan\phi = \frac{2y}{x}$ or $\frac{8d}{a^2} x$ or $\frac{8x}{an}$.

Uniform dead load.

If w = uniform dead load on cables per foot run of bridge (including troops, roadways, slings, &c.)—

Formulæ for whole cable.	Formulæ for any point P.
Tension $T_o = \frac{wa^2}{8d}$ or $\frac{wan}{8}$.	
Tension $T_H = T_o \sec\theta$.	$T_P = T_o \sec\phi$.
$= w\frac{a}{2}\sqrt{1 + \left(\frac{a}{4d}\right)^2}$.	$= w\sqrt{x^2 + \left(\frac{a^2}{8d}\right)^2}$
or $w\frac{a}{2}\sqrt{1 + \left(\frac{n}{4}\right)^2}$.	or $w\sqrt{x^2 + \left(\frac{an}{8}\right)^2}$.
Pressure $C_H = wa$	
Length of cables between piers. $l = a + \frac{8d^2}{3a}$.	Length from O to P $z = x + \frac{2y^2}{3x}$.
$= a + \frac{8a}{3n^2}$.	

One pier higher than the other.

If one pier KH is higher than the other K_1H_1, let span $KK_1 = a_1$. Then $x_1 = \dfrac{a_1\sqrt{y_1}}{\sqrt{d} + \sqrt{y_1}}$ and $\frac{a}{2} = a_1 - x_1$. All the above formulæ can then be used. The length of the cables

$$HOH_1 = \frac{l}{2} + z_1 \text{ or } a_1 + \frac{2}{3}\left[\frac{2d^2}{a} + \frac{y_1^2}{x_1}\right] \text{ or } a_1 + \frac{2}{3}\left[\frac{2a}{n^2} + \frac{y_1^2}{x_1}\right].$$

Concentrated load in addition to uniform dead load.

If W = a concentrated load in addition to the uniform load w, let S = sum of all loads on bridge = $W + wa$. Then

$$\text{maximum } T_H \text{ (when } W \text{ is at O)} = \frac{1}{2}\sqrt{S^2 + \left\{\frac{a}{4d}(S + W)\right\}^2}$$

$$\text{or } \frac{1}{2}\sqrt{S^2 + \left\{\frac{n}{4}(S + W)\right\}^2}$$

maximum C_H (do.) = S.

Increase of dip caused by W is $d\left\{\frac{S + W}{\sqrt{(S + W)^2 - SW}} - 1\right\}$.

Increase of dip caused by elongation of cable (e) is :—

$$\frac{3a}{16d}e \text{ or } \frac{3n}{16}e.$$

6. The following table will be found useful for calculating stresses due to uniform loads on suspension bridges; in it the load is $w \times a$:—

1. Dip.	2. Tension at lowest point.	3. Tension at highest point.	4. Length of cable be-ween the piers.	5. Depression at centre due to an elonga-tion of cable of 1 inch.	6. Value of JK.	7. Value of JH.
$\frac{a}{10}$	1·25 × load	1·346 × load	1·027 × span	1·875 inches	2·5 HK	2·7 HK
$\frac{a}{11}$	1·375 "	1·46 "	1·022 "	2·0625 "	2·75 HK	2·93 HK
$\frac{a}{12}$	1·5 "	1·58 "	1·0185 "	2·25 "	3·0 HK	3·17 HK
$\frac{a}{13}$	1·625 "	1·7 "	1·0158 "	2·4375 "	3·25 HK	3·4 HK
$\frac{a}{14}$	1·75 "	1·82 "	1·0136 "	2·625 "	3·5 HK	3·64 HK
$\frac{a}{15}$	1·875 "	1·94 "	1·012 "	2·815 "	3·75 HK	3·88 HK

7. The formula $y = \frac{4d}{a^2}x^2$ or $\frac{4x^2}{an}$ is used when it is required to trace the curve or find the length of the slings. Thus in a 200-feet bridge with a dip of 20 feet, at a distance of 50 feet from the lowest point,

$$y = \frac{4 \times 20}{200^2}50^2 = 5 \text{ feet, where } \begin{cases} a = \text{span in feet.} \\ d = \text{dip in feet.} \\ y = \text{length of sling in feet.} \\ x = \text{distance from lowest part in feet.} \end{cases}$$

In this way the following table of ordinates for different values of x and different dips has been calculated:—

Dip d.	Value of y when x =								
	$\cdot 1\frac{a}{2}$	$\cdot 2\frac{a}{2}$	$\cdot 3\frac{a}{2}$	$\cdot 4\frac{a}{2}$	$\cdot 5\frac{a}{2}$	$\cdot 6\frac{a}{2}$	$\cdot 7\frac{a}{2}$	$\cdot 8\frac{a}{2}$	$\cdot 9\frac{a}{2}$
$\frac{a}{10}$	·001a	·004a	·009a	·016a	·025a	·036a	·049a	·064a	·081a
$\frac{a}{11}$	·0009a	·0036a	·0082a	·0146a	·0227a	·0327a	·0445a	·0582a	·0736a
$\frac{a}{12}$	·0008a	·0033a	·0075a	·0134a	·0208a	·03a	·0408a	·0533a	·0675a
$\frac{a}{13}$	·0008a	·0031a	·0069a	·0123a	·0192a	·0277a	·0377a	·0492a	·0623a
$\frac{a}{14}$	·0007a	·0029a	·0064a	·0114a	·0178a	·0257a	·035a	·0457a	·0579a
$\frac{a}{15}$	·0007a	·0027a	·006a	·0107a	·0167a	·024a	·0327a	·0427a	·054a

Common suspension bridge.

Common suspension bridge.

8. The roadway hangs below the cable, and consists of transoms, road-bearers, chesses, and ribands. This is suitable for all kinds of traffic, but requires more material than the trestle or ramp-suspension bridges.

This type of suspension bridge is shown in Pl. L., Fig. 1, where the bridge has a span of 200 feet, a dip of $\frac{1}{10}$th of the span and a width of roadway of 5 feet 8 inches in the clear, so that the ribands may act as wheel guides. In this case the whole roadway hangs from the cables, which should be at least 1 foot above the road at the centre, and should allow a camber of $\frac{1}{80}$th of the span. The cables are supported on timber piers (Fig. 9) with a broad cap of hard wood, trenailed and dogged to the top of the legs, and grooved to receive two plates (Fig. 3) on which the cables rest, 9 feet 6 inches apart.

Roadway.

The roadway consists of transoms, carrying road-bearers which support chesses (Fig. 4) racked down witb double ribands. If the bridge is for heavy traffic, two struts, B, footed on the banks, are used to diminish the distortion; the first transom is carried entirely by the ties E and the struts B. The second is chiefly, and the third partly, supported by these struts.

Construction of bridge.

9. In all cases when the working parties cannot pass from bank to bank at the site of the bridge, time is saved by stretching a line across, as in Pl. LII., Fig. 7, with a block to travel on it and take rope ends, &c., backwards and forwards.

The line of bridge is fixed, and the anchorages marked out and commenced, by four men at each side, while two men prepare the footings for the piers on each side. These piers consist of a frame with side and back struts (Pl. L., Figs. 1 and 9) and back guys. These guys allow of the piers being placed close to the edges, thus shortening the span. When the piers are put further back from the edges, the back guys may be replaced by front struts.

The piers are framed together (the distance apart of the legs being governed by the nature of the traffic), the back struts are laid out in rear of the frames, and lashed loosely at their tips to the legs below the caps. The back guys are also secured round the caps, just inside the cable bearings, which should be exactly over the centres of the legs. The anchorages are as shown in Part IIIA., Pls. XXIX. and XXXIV. For their holding power see Part IIIA., Sec. V., para. **15.** The ties are taken round these anchorages, but not finally secured. A couple of guys are also secured to the heads of the legs, and the bearings are greased. While this is being done the cables are passed across and laid on either side of the positions of the frames, and secured, if necessary, to pickets. The frames are now raised by hand, props being employed at each lift till the back struts can be used. In the case under consideration the use of fore-guys for this purpose would be inconvenient, but with shorter spaces they should be used.

When the frames are up and hanging forward on the back guys, the back struts are put into their footings, the frames being pulled back a little towards the bank. The slack of the back guys is now taken in, and they are secured; and while each cable is being raised, a side guy is used on the further side (and in the plane) of the frame to steady it.

10. To raise the cables at the first pier, a double and treble, or single and double, tackle, with a 3-inch fall, is secured to the tip of each of the poles which are to act as side struts; these poles are then raised up alongside the legs (Pl. L., Fig. 9), and two men go up by the back guys and lash the poles to the cap just inside the cable plates. A long *bridle* of spun yarn is used (Fig. 10), secured to each cable in front and in rear of where it should bear on the cap, and the lower block of each tackle is hooked to the bridle on its own side; a snatchblock is also lashed to each leg, 3 feet above the ground, and the running end of each fall led through it to the rear. The cable ends being sufficiently secured, the cables are now raised, dropped into their places, and cleared of the bridles. The blocks are then transferred to the cap, where they are secured near the cables, and the spars are partly unlashed and their feet drawn out till they are in their proper positions as struts. Their feet should be let into the ground, and should rest on a timber footing. They are then finally lashed to the legs and cap. **Raising the cables.**

With heavy piers a derrick will be required to raise them to a vertical position. In this case the derricks should be made of such a height as will allow them to pick up and place the cable before the tackle becomes chock.

11. By this time the anchorages should be ready. The bottom sheeting piece is placed first, then the cable ends on one side are passed round the beam B, the sheeting pieces added after the turns have been taken, and the earth is filled in and rammed. (Part IIIA., Pl. XXXIV., Fig. 4.) The squads may now go over to help on the other side, and return **Making fast to anchorages.**

when the cables are taut. The other ends of the cable are now passed round their anchor beam, B, and seized, but without taking in the slack, and the anchorages are sheeted and filled up, with the exception of the grooves. The arrangements for raising the cables on the second pier are the same as before, except that treble and double tackles are required. When the cables are placed and the pier completely strutted, a treble block is hooked to a strong selvagee which grips the standing part of the cable; the double block is similarly secured near the anchorage to the running end which has been taken with a complete turn round the anchor beam B. Each fall is then manned and the slack is taken in,* a man at each anchorage easing round the turns; if these jam, the standing part can be hauled in by fastening the double block to the anchor beam. The cable should be hauled up till the dip is $\frac{1}{11}$, or less; this can be ascertained by nailing horizontally straight edges at the corresponding height on the uprights of the piers and sighting the bottoms of the curves.

The cable ends are now seized to their standing parts by either of the following methods :—

Seize the running end of the cable strongly to the standing part with tarred yarn nearly up to the extremity of the running end. The wires of this end are then opened out, bent back over the seizing, and fresh seizing is passed round them and the standing part so that they form a plug.

Another method is to seize the running end to the standing part by means of clips made of wrought iron, as shown in Part IIIA., Pl. XXIX., Figs. 1 and 2. The cables are placed in the clips, and the wedges squeezed in between them. The cup is then placed under the lower cable, the bottom plate put on, and the whole screwed up by means of the nuts, after which the wedges are jammed by means of the outer screws, these clips are very convenient for later adjustment of cables.

Placing transoms.

12. The ends of the ties E (Pl. L., Fig. 1) are passed over the piers and a traveller for placing the transoms is constructed as follows : A 14-foot spar (about 3 inches or 4 inches in diameter), with two 20-foot rope ladders attached to it (each about 4 feet from the centre of the spar), is now raised hy the pier blocks, its end passed over the cables, and preventer ropes secured to each end are taken over the pier heads and down below so as to be let out as required. A man with two 1-inch lashings then goes up each

* It has been found, experimentally, that with wire ropes the effective power required to haul them in over the pier-caps is about 33 per cent. greater than the theoretical stress at the highest point. Thus, in this case, to draw up a cable of 26·5 lbs. weight per fathom to a dip of $\frac{1}{12}$th, the stress

$$= 1{\cdot}58 \times 200 \times \frac{26{\cdot}5}{6} \text{ lbs.} = 1{,}400 \text{ lbs.}; \text{ adding 33 per cent., we get}$$

$$1{,}400 + \frac{33}{100} \times 1{,}400 = 1{,}862 \text{ lbs., the power required.}$$

ladder and by supporting his weight on the cable, eases down the *traveller* until it is below the point C. A tackle may be suspended from the traveller to raise or lower the load it carries as required. Instead of these travellers, a chess may be slung by ropes from shackles similar to that shown in Pl. L., Fig. 8, working on each side.

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

The butts of the spars are then lowered into footings prepared for them, which should be deep, so that the spars cannot be jerked out of them when the load comes on the far end of the bridge. The men on the ladders at once lash the tips to the cables at C, and at the same points secure the slings for the second transom; they also fix the ends of the falls of the pier blocks to their spar, and cast off their preventer ropes.

The ties E, are now made taut, and the roadway made out to D; the second transom is then secured to its slings at the proper height, and the roadway extended to it. Much time is saved if slings in a single piece and of the proper length are used. The length of each sling should be calculated from the formula $y = \frac{4d}{a^2}x^2$ (para. 7), and allowing for the slope of the roadway.

13. The slings are attached to the transoms by a clove hitch and seizing. Shackles if available are very convenient for attaching the slings to the cable, being prevented from slipping along the latter by means of a stopper of spunyarn. If they are not available, the best attachment is a round turn and seizing. This allows the sling to be easily adjusted if desired, Pl. L., Fig. 7 and 8. Attachment of slings.

Another form of fastening is the screw clamp, shown in Fig. 6, where a couple of plates about $2\frac{1}{2}'' \times \frac{3}{16}''$ are clamped to the cable. When two or more cables are used, the slings can be attached to them by means of saddles made of cast iron as shown in Pl. LI., Fig. 4, which can be prevented from slipping in the same manner as shackles. In the centre of the saddle is a conical hole, and the suspending wire is attached to it by passing it through the hole, opening out the strands, driving in a plug of cast iron, and running in the interstices between the wires with hardened lead. A stirrup on the same principle, and connected to the sling by the same method (Fig. 5), can also be used for supporting the road transoms. Even when there are no shackles or clamps or saddles, it is better not to tie the slings to the cables, but to stopper them as above, as their position can then be more quickly shifted when required. In this way, by means of the travellers working from both ends, all the slings are fixed along the cables at the required intervals, the transoms supported, and two road-bearers placed at each bay, so as to carry four or five chesses.

Adjusting slings.

The slings must now be adjusted. To commence, the traveller or a similar spar is brought directly above the third transom, which is raised or lowered by means of a tackle from the traveller. The slings are then secured to the transoms (in the case of a single sling) by a round turn and seizing (Pl. L., Fig. 8).

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

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

Forming roadway.

14. The roadway is now formed by adding the outer road-bearers, which are spliced as in Pl. L., Fig. 2, only with a shorter splice; the undersides of the ends may be flattened, and the splice is securely lashed with 1-inch lashings to the transom, which may also have cleats for the road-bearers, and 1-inch trenails to keep the slings on (Fig. 4). The inner road-bearers which overlap are placed not more than 12 inches inside each outer one, the chesses are laid down, and as the outer road-bearers are continuous, the ribands can be laid continuously over them; these may consist of 5-inch or 6-inch spars, the lower one flattened on both sides, and the upper on one side. They should be in long lengths 20 to 30 feet, and break joint. After the final adjustment of level both are racked together to the outer road-bearers as shown in Fig. 1. These deep ribands stiffen the roadway, and take much of the weight off the outer road-bearers; they also act as wheel guides.

Rack-lashings may be protected by wooden cleats nailed to the ribands, which prevent the wheels from cutting them.

Stiffening guys (para. 4) to most of the transoms should be added, the travellers, blocks, and tackles taken down, and the bridge is ready for use after the fastenings of the cables and slings have been carefully inspected.

If suitable material be available the stiffness of the bridge may be increased by bracing the handrail to the roadway; or by the use of inverse catenary ropes which in plan should have a splay outwards from the centre; by this means lateral as well as vertical sway is checked

Organisation of labour.

15. The following is the organisation of the working parties in each relief of eight hours; smaller numbers could do the work but more slowly:—

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

* In some cases 40 to 50 men may be required if the cables have to be moved far. Cables can be carried where wheel traffic cannot pass.

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

3rd Relief.—20 men, 10 on each side, placing transoms; 10 men preparing and bringing up road superstructure.
4th and 5th Reliefs.—20 men adjusting transoms and main cables.
6th Relief.—30 men laying roadway, racking down, and completing bridge.

16. As an example take a bridge for infantry in file span 200 feet dip $\frac{1}{10}$. The superstructure will weigh 100 lbs. per foot run. **Example.**

Traffic load = 280 lbs. per foot run.
= 420 lbs. equivalent dead load.

$\therefore$ Total dead load = 520 lbs. per foot run.

$$\text{Then tension at highest point} = \frac{wa}{2}\sqrt{1 + \left(\frac{n}{4}\right)^2}.$$

$$\text{substituting} = \frac{520 \times 200}{2}\sqrt{\left(1 + \frac{10^2}{16}\right)}.$$

$$= 140{,}400 \text{ lbs.}$$
$$= 62{\cdot}6 \text{ tons.}$$

Or using the table, para. **6**,

$$\text{Tension at highest point} = 1{\cdot}346 \times wa.$$
$$= 1{\cdot}346 \times 520 \times 200.$$
$$= 139{,}984 \text{ lbs.}$$
$$= 62{\cdot}5 \text{ tons.}$$

The thrust on the legs of each pier $= wa = 104{,}000$ lbs.

The height of the piers = dip + camber + length of shortest sling.

The size of the cable required is obtained from the formula:—

$9c^2$ = working load in cwts. (Part IIIA., Sec. IV., para. **32**.)

$$= \frac{62{\cdot}5 \text{ tons}}{2} \times 20.$$

whence c = 8 inches.

The length of the cable

= length between piers.
+ 2 length JH (Pl. LI., Fig. 6).
+ sufficient spare end to make fast at anchorages.

The cable being 8″, the drum of the anchorages must be 8″ × 4 = 32″ (Part IIIA., Sec. IV., para. **35**), therefore about

13 feet of length will be taken up on the drum : and about 40 feet will therefore be required for making fast.

Therefore length of cable

$= 1{\cdot}027 \times \text{span} = 1{\cdot}027 \times 200$ (Para. **6**, col. 4).
$+ 2 \times \text{JH} = 2 \times 2{\cdot}7\,\text{HK} = 2 \times 2{\cdot}7 \times 24$ (Para. **6**, col. 7).
$+ 2 \times 40.$
$= 415$ feet or 70 fathoms.

The pull in the anchorages is equal to the tension in the cables at the piers acting at a slope of $\frac{1}{2\cdot5}$ (Para. **6**, col. 6).

If in addition to the infantry traffic, a G.S. wagon was to be run over by hand the calculation would have been modified as follows :—

Weight of wagon $= 5{,}610$ lbs.

deduct weight of infantry over space occupied by wagon

$= 14 \times 280 \qquad = 3{,}920$ lbs.

additional live load due to wagon $= 1{,}690.$
equivalent dead load $= 2{,}535.$
$= 1{\cdot}13 \text{ tons} = \text{W}.$
Uniform dead load due to infantry $= wa = 104{,}000$ lbs.
$\therefore \text{S} = 106{,}535$ lbs.
$= 47{\cdot}6$ tons.

Maximum tension in cable

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

$$= \tfrac{1}{2}\sqrt{47{\cdot}6^2 + \left\{\frac{200}{4+20}(47{\cdot}6 + 1{\cdot}13)\right\}^2},$$

$= 65{\cdot}4$ tons.

Ramp suspension bridge.

Ramp suspension bridge. **17.** In this type the roadway rests for the most part directly on the cables and consists of chesses and ribands only, road-bearers being required for one bay only at each end. This reduces the load due to superstructure very considerably, but as there is a corresponding want of stiffness a bridge of this type is suitable for dismounted troops and light carriages only. It requires less time and material for construction than other forms of suspension bridge.

The example of this type of bridge given in Pl. LI., Fig. 1, provides a roadway the slope of which does not exceed $\frac{1}{8}$, and at the same time uses as much of the cables as possible to take the chesses directly upon them.

The span is 100 feet and the dip $\frac{1}{10}$. The roadway is 5 feet 8 inches wide between the ribands, so as just to take field guns (Figs. 3 and 7). The cables are 7 feet apart at the piers, and the anchorages consist each of a buried log (Fig. 2).

With a load of infantry, in file, crowded, such a bridge has a stress of about 63,000 lbs. in the cables, and on the anchorages.

Measurement of dip.

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

As an alternative method pieces of spun yarn may be lashed to the wire cables, at a distance apart equal to the calculated lengths of those cables. The cables should then be hauled in or let out, so as to keep the pieces of spun yarn over the piers. By this means, also, any tendency to slip may be at once detected.

If the cables are hemp, they must be tautened as much as possible when first placed. When tbe roadway is partly formed, they may be stretched again by weighting it, after which they must be tautened to somewhat less than the working dip.*

In case guns have to pass such a bridge, and the chesses are not thick enough when only resting on the cables, the transoms A, B, C, D, &c., may be heavy (5 inches instead of 3 inches or 4 inches), and lashed loosely to the cables, so as to hang 3 inches below them. One or two baulks can then be laid from transom to transom along the roadway, so as to give the necessary support to the chesses or side baulks.

When the piers must be so high that a cable transom would interfere with the use of the bridge, they should be designed as shown in Pl. LI., Fig. 1. For infantry only, sloping banks may be stepped (Fig. 2) and thus piers may be omitted while the slope of the roadway is not excessive.

Trestle suspension bridge.

18. In this type of bridge the roadway is carried on trestles supported on the cables of the bridge. The superstructural load absorbs a large proportion of the strength of the cables, but at the same time a given traffic load distorts the bridge less than either of the foregoing types. It requires no high piers but is very susceptible to wind pressure and unless the height of the banks of the gap is greater than the dip, the centre of the cables may also be subject to pressure of water. The superstructural load must be estimated spar by spar, use being made of chart, Pl. XV., Part IIIA.

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* A load of ⅓rd the B.W. stretches 100 feet of hawser to 109 feet.

Trestle suspension bridge.

19. The bridge (shown in Pl. LII., Figs. 1 and 2) has a span of 130 feet and a dip of $\frac{1}{12}$; the roadway rises 1 in 30, and is 5 feet 8 inches wide in the clear, the cables being 10 feet apart, and the anchors each 18 feet by 18 inches. The roadway is supported on trestles which form equilateral triangles, each side being 10 feet (height 8 feet 9 inches). As it appears desirable not to employ trestles much higher than this, low piers are used, so that trestles of this height will suffice at the centre (Figs. 1 and 8); while with spans of less than 100 feet piers may be dispensed with, as in Pl. LI., Fig. 2.

The cables are first got out and anchored. The ordinates of the curve of a cable having been calculated (para. **6**), it should be traced out on the ground, and the frame-legs (Fig. 4) laid on the section, and marked where they cross the roadway and cable.

The trestles for each half span, when formed, are ranged in order on their own bank; connected together as they are placed on the cables, and boomed and hauled out to the centre. The two centre frames are joined, the dip of each cable adjusted, and the bridge completed.

When only a single point of support is wanted, a single four-legged trestle may be used as in Pl. LIII., Fig. 2.

Organization of working parties.

20. The following is the organization of labour for eight hour reliefs :—

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

2nd Relief.—40 men, 20 on each side, securing and tightening cables, and afterwards getting out trestles.

3rd and 4th Reliefs.—20 men adjusting trestles.

5th Relief.—30 men forming roadway, racking down, and fixing guys, handrail, &c., and making up bridge ends.

21. The following table gives the stores and materials required for the three suspension bridges described in paras. **8** to **19** in addition to those special to each which are given in paras. **22** to **24** :—

Description.	Number or quantity for the		
	200 feet.	100 feet.	130 feet.
STORES.			
Augers, ½-in., for dogs	2	2	2
,, 2-in., for trenails	1	1	1
Axes, felling, helved	1	1	1
,, pick	16	8	8
Blocks, double } with 3-in. (white) rope			
,, treble } with 3-in. (white) rope	4	4	4
,, snatch, 8-in. (for 3-in. rope)	5	1	8
Dogs, iron, ⅝-in. round, 12-in. with 6-in. spikes ...	32	56	64
Files, saw, 3 square { hand	1	1	1
Files, saw, 3 square { cross cut	1	1	1
Handspikes, 6-ft.	4	2	2
Levels, field service	1	1	1
Mauls	2	2	2
Posts, picket, 5-ft.	4	4	4
Rods, 6-ft. measuring	2	2	2
Saw, cross cut, 5-ft....	1	1	1
,, hand, 26-in.	1	1	1
Sets, saw { hand	1	1	1
Sets, saw { cross cut	1	1	1
Shovels, universal, helved...	16	8	8
Tapes, measuring	2	2	2
MATERIALS.			
Cables (3-in.), 30 fathoms long	4 to 8	4 to 8	4 to 8
Cable seizings of yarn (strong), 3 fathoms each ...	16	12	12
Chalk, pieces	4	4	4
Fascines, 18 ft. by 9 in.	12	10	10
Grease, lbs., for bearings and saws	4	2	4
Lashings, 2-in., 8 fathoms each	12	4	9
,, 1½-in., 5 fathoms each...	10	12	104
,, 1-in., 3 fathoms each	100	30	280
Lines, Hambro'	2	1	1
Pickets, bundles of	2	2	4
Planks, 7 ft. 6 in. by 12 in.	200 (1½ in.)	100 (2 in.)	130 (1½ in.)
Plates, iron (bent), 3 ft. by 3 in. by ¼ in.	4	—	4
Racksticks or wedges	100	0	84
Selvagees, spun yarn	36	5	5
Spikes, iron, 9-in.	8	20	32
,, ,, 6-in.	12	0	8
Tapes, tracing	2	2	3
Thread, pack, balls	1	1	1
Trenails, oak (2-in.), 12 in. long	8	8	8
Yarn, spun	1 cwt.	28 lbs.	56 lbs.

22. Materials and tools for the common suspension bridge (para. **8**) in addition to those given in para. **21**:— Materials, &c., for suspension bridge of 200 feet span.

Two 5½ in. steel wire hawser-laid cables, each 68 fathoms.
Four spars 26 ft. (10 in. at tip) for legs.
Four ,, 22 ft. (3½ in. at tip) for diagonals.
Two baulks 12 ft. × 10 in. × 9 in. of hard wood, for caps.
Two ,, 15 ft. × 10 in. × 10 in. for ground sills.
Four spars 36 ft. (4 in. at tip) for back struts.
Four ,, 32 ft. (3 in. at tip) for side struts.
Four ,, 30 ft. (5 in. at tip) for cable props.
Two ,, 30 ft. (3 in. at tip) for horizontal frame ties.
Forty spruce spars 20 ft. (6 in. throughout) for ribands.
Eighty ,, 13 ft. (6 in. throughout) for road-bearers.
Nineteen ,, 10 ft. (6 in. throughout) for transoms.

Two spars 10 ft. (over 4 in.) for shore transoms.
Two „ 14 ft. (4 in. throughout) for travellers.
Four hundred feet run of planking 12 in. × 1 in. for wheel planks.

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

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

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

23. Materials for the ramp suspension bridge (para. **17**), in addition to those in para. **21**:—

Two 10-in. hemp, or 6-in. iron wire cables, each 28 fathoms.
Two spars 18 ft. (15 in. throughout) for anchors.
Four „ 25 ft. (6 in. at tip) for road-bearers.
Seven „ 12 ft. (6 in. throughout) for transoms.
Ten „ 20 ft. (4 in. throughout) for ribands.
Two „ 9 ft. (over 4 in.) for shore transoms.
Forty rack sticks and lashings (8 ft.).

Two baulks 15 ft. × 8 in. × 8 in. sills		Piers.
Four „ 3 ft. × 8 in. × 8 in. struts (inside)		
Four „ 2 ft. × 8 in. × 8 in. caps		
Four „ 5 ft. × 8 in. × 8 in. uprights		
Four „ 6 ft. × 8 in. × 8 in. struts (outside)		
Four „ 7 ft. × 8 in. × 4 in. back struts		
Two 10 ft. to 15 ft. × 8 in. × 4 in. anchors		

Materials, &c., for suspension bridge of 130 feet span.

24. Materials for the trestle suspension bridge (para. **18**), in addition to those in para. **21**:—

Four $8\frac{1}{2}$-in. hemp, or two $4\frac{1}{2}$-in. steel wire cables, each 36 fathoms.
Two logs 18 ft. (18 in. diameter throughout) for anchors.
Forty-four spars 13 ft. (3 in. at tip) for trestle legs.
Forty-four „ 15 ft. (2 in. at tip) for diagonals.
Twenty-two „ 10 ft. (6 in. throughout), transoms.
Eight spars 12 ft. (2 in. throughout), ledgers.
Twenty „ 12 ft. (6 in. throughout), cable ledgers.
Two „ 10 ft. (5 in. throughout), shore transoms.
Forty „ 14 ft. (5 in. throughout), road-bearers.
Eight „ 16 ft. (6 in. throughout), „

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

Twenty-eight spars 20 ft. (5-in. round flatted) for ribands.

Two baulks	18 ft. × 10 in. × 10 in. sills	Piers.
Four ,,	3 ft. × 10 in. × 10 in. uprights	
Four ,,	2 ft. × 10 in. × 10 in. caps	
Four ,,	4 ft. × 10 in. × 10 in. struts (outside)	
Four ,,	2 ft. 6 in. × 10 in. × 10 in. ditto (inside)	

Four ,, 7 ft. × 8 in. × 4 in. back struts.
Two ,, 10 ft. to 15 ft. × 8 in. × 4 in. anchors.

Stiffened suspension bridges.

25. The common suspension bridge is very liable to distortion under a partial traffic load.

The greater the dip of the cables, the greater will be the distortion produced by the moving load, and therefore the dip has to be kept small, generally not more than 1/10 and often less, although this leads to a great sacrifice of constructional economy.

By using two cables on either side of the bridge and by combining these two cables into what are practically girders very stiff suspension bridges can be produced. An example of this form of construction will now be described.

26. The principle of this method will be best understood by a reference to the diagram. (Pl. LIV., Fig. 1.) Let AB represent the tops of the piers, and let ACB be a parabola, having any required dip, CD, at the centre. Join AC and BC. These will represent the upper members of each semi-rib. The lower members, AEC, BFC, are found by determining a series of points, E, F, such that their vertical distances to the original parabola are equal to the distances between the upper members and the original parahola in the same vertical planes. The original parabola will thus become the neutral axis of the rib, that is, the line which everywhere bisects its vertical depth. Example.

These ribs are then divided into panels by vertical struts at intervals, preferably at the points of attachment of the slings, and cross-bracing ties added to each panel, as shown in Fig. 2. The slings can be attached either to the lower or to the upper member. The latter involves the transmission of the stress through the cross-bracing, and the former thus seems to be better.

As rigidity is secured by this design, the dip of the neutral parabola is only limited by the permissible height of the piers; and by increasing the dip, considerable economy can be introduced.

As regards erection, this type of bridge does not differ materially from the ordinary kind, but a few points may be noted.

27. The parabolic semi-ribs, or cable girders, should be constructed on shore. For this purpose a series of park pickets, or Construction of cable girders.

other stout pickets, should be driven into the ground to represent the various panel points, as shown in Fig. 3. Their positions are best found from a base line and ordinates, and the greatest care must be taken to lay out the girders as accurately as possible, to avoid initial stress in the diagonals when they are placed in position in the bridge. It is especially necessary to ensure that the girders are made the same horizontal length as the distance between the piers. It is advisable to place a group of three pickets at each of the points representing A, B, and C, and also to stay them back to another picket, as a considerable amount of stress will come upon them in the process of taking the stretch out of the cables. This is done by securing a tackle to each end of each cable, as shown in the figure, differential tackle, if available, being very convenient. When the cables have been thus stretched in position, the diagonals and verticals are lashed to them very securely, endeavouring to make the various members meet as far as possible in the calculated panel points. It is more convenient, in the subsequent erection, if these spars project no more than is necessary beyond the cables.

The cables must be securely fastened together where they cross, at the point C, as the rigidity of the structure, when the load is not uniformly distributed, depends on the cables not slipping at this point. Some form of bolted clip is best. This joint should be made and secured to the group of pickets at C, before applying the tackles to the free ends of the cables.

The points of attachment of the various slings should be marked with paint, in case the cross-bracing should get displaced, and the portions of the cables that are to rest on the piers should be similarly marked. For convenience in subsequent handling, the cables may be secured together at the points A and B.

When one cable girder has been completed, it is lifted off the framework, and the other one then made.

Launching girders.

28. These girders are best put into position by being launched along a ropeway, stretched from a derrick on each bank, by securing slings to the upper panel points and attaching these slings to snatch-blocks travelling on the ropeway, care being taken to keep the girders in their proper shape, to avoid undue stresses in the bracing.

Securing cables to anchorages.

29. Each cable is taken separately round the anchorage, and secured as before described after being adjusted so that the portions marked are over the piers.

The following method of securing the cables was used in a bridge made at Chatham and was found very convenient for making the final adjustments. Each cable was taken round the anchorage without a round turn, and secured by two bolted clips. The cables were pulled up a little above their final position, and when the bridge was completed, were adjusted with great accuracy, by loosening the clip further from the anchorage, passing an inch or so of the cable through it, and tightening it up again ; the other clip was then loosened a little, thus allowing the slack in the cable to run through slowly, and then tightened again. This operation was repeated until the girders were adjusted.

Placing slings.

The operation of placing the slings and transoms is not quite so easy as in the ordinary type of suspension bridge. By building out the bridge bay by bay, they can be put on the cables and allowed to slip out to their positions, being automatically stopped by the bracing at the right place.

This type of bridge requires more labour than the ordinary suspension bridge; but if sufficient labour is available the time required is not greater.

The following labour data for such a bridge was recorded at Chatham :—

The span of the bridge was 90 feet, the bays were 10 feet, and the dip was 1/10. It was designed to carry infantry in fours. The necessary timber was available in suitable scantlings, and carpenters' labour was only required for framing the piers out of 12″ × 12″ baulks.

The total amount of labour required was 616 man-hours, approximately 7 man-hours per foot-run of bridge, a figure that compares favourably with the other examples of suspension bridges given in this book.

The labour required was made up as follows :—

	Man-hours.
Making cable girders	58
Erecting ropeway...	33
Anchorages	51
Framing and erecting piers	125
Launching cables and general work till completion	349
Total	616

It was found that a party averaging 25 men could be employed, and therefore the bridge ought to be completed in about 24 hours. The total time actually taken was about 29 hours.

Calculations for stresses.

30. The stresses in the members of these girders can be calculated from the following formulæ in which—

p = cwt. of superstructure per foot run.
q = equivalent cwt. of dead traffic load per foot run, or
$p + q = w$, total distributed load.
a = span in feet.
$d = \frac{a}{n}$ = dip of neutral parabola at centre of span.
b = breadth of one bay.

Maximum tension in lower member—

$$= (p+q)\,\frac{a^2}{16d}\sqrt{1+\left(\frac{6d}{a}\right)^2};$$

$$\text{or} = \frac{(p+q \quad a\times n}{16}\sqrt{1+\left(\frac{6}{n}\right)^2}.$$

Maximum tension in upper member—

$$= \frac{a^2}{16d}\ \{p + q(1 + \ )\ \}\ \sqrt{1 + \left(\frac{2d}{a}\right)^2},$$

$$\text{or} = \frac{(p + \frac{3}{2}q)an}{16}\ \sqrt{1 + \left(\frac{2}{n}\right)^2}.$$

Which of these two is the greater depends on the proportion of p to q, and on the proportion of dip to span, though for usual values it will be found that the maximum tension in the upper member will be the greater, and will thus determine the size of the cables. As pointed out above, the value given to q in this calculation must be the maximum possible, as the strength of the structure is involved, and not merely its rigidity.

The horizontal component of the maximum stress in any diagonal due to any distribution of the moving load is

$$\tfrac{1}{2}\left(\frac{qa^2}{16d}\right)\left(\frac{2b}{a + 2b}\right) = \tfrac{1}{2}\left(\frac{qan}{16}\right)\left(\frac{2b}{a + 2b}\right)$$
$$= \frac{q \times a \times n \times b}{16\ (a + 2b)}$$

where b is the breadth of the panel. The division by 2 is necessary, as the bridge is suspended from two cable girders, one on each side of the roadway.

To find the direct stress, this expression must be multiplied by the secant of the inclination of the diagonal to the horizontal. This inclination varies with each diagonal in every panel, but sufficient accuracy would be obtained by taking an average inclination ϕ, where ϕ is

$$\tan^{-1}\frac{d}{2b}.$$

Stresses found by graphic method.

31. The stresses can, however, be found graphically, more accurately, and almost as quickly. If the scale for the stresses be so chosen that b, the panel breadth, represents the horizontal component, then the lengths of the various diagonals, to the same scale, will represent the direct stresses in them.

With a single system of bracing, the stress in each vertical would be the vertical component of the direct stress in the corresponding diagonal, but with the system of cross-bracing this stress may be greatly reduced.

In determining their cross-sections, however, it is better to take into account the full stress, which can be found graphically with sufficient accuracy, from the length of the verticals, using the same scale for these stresses, as before. The verticals should be strong enough to bear this stress in compression.

The case of a concentrated weight, or a series of concentrated weights, crossing the bridge, will not be considered at any length.

It is sufficient to say that the calculated safe strength of the cables will not be exceeded if the concentrated weight on any one bay does not exceed qb, q being the maximum value of the distributed traffic load and rigidity will not be lost if the concentrated weight of each bay does not exceed $2pb$, where p is the dead weight of the structure per unit of length, and then only if coincident with the worst case of loading, that is to say, one-quarter of the span being covered, the remainder clear of traffic.

The thrust on the piers, the inclination of the cables from the piers to the anchorages, and the strength necessary in the anchorages, can all be calculated as though the rigid system were replaced by a single cable, hanging in the neutral parabola. The piers must be carefully strutted and stayed to withstand the varying stresses due to a moving load.

The length of each cable of the rigid system can he taken with sufficient accuracy as that of a cable in the neutral parabola, the usual allowances being made for length required at the anchorages and so forth.

The length of the slings can be found graphically or by calculation, in either case making the necessary allowances for the camber of the roadway, and the length of the shortest sling, noting, however, that in this type of bridge, the central sling will not be the shortest, but that there will be two shortest slings, real or imaginary, one from the vertex of each parabolic lower member, at a distance from the abutment on each side equal to $\frac{3}{8}$ths of the span.

Calculations for length of slings.

32. The other method is to make use of the equation derived from the mode of construction, which gives the length of each sling, measured from the horizontal tangent at the vertex of the neutral parabola, as

$$\frac{8d}{a^2}x^2 - \frac{2d}{a}x, \text{ or } \frac{8x^2}{an} - \frac{2x}{n},$$

x being measured either way from the vertex of the neutral parabola.

The other calculations necessary, such as strength of slings, transoms, road-bearers, and anchorages, are identical with those required in the normal type.

Stiffeners an[d] wind guys.

33. The stiffness given by this construction is only in the vertical plane, and that lateral stiffness must be given by any of the usual methods, such as horizontal wind-ties, or horizontal girders. Sufficient lateral stiffness might perhaps be obtained by giving the bridge a "waist" in plan.

Example.

34. To construct a bridge of 100 feet span, 10 feet bays, dip 1/8, to carry infantry in fours. This example is comparable with a bridge erected at Chatham, for which certain data as to the labour required are given above (para. **29**). Only calculations are given when they differ from the normal type.

The dead weight of the structure may be estimated as follows:—

Cables and slings	15 lbs. per foot run.	
Road-bearers	50 ,,	,,
Transom	20 ,,	,,
Planking	65 ,,	,,
Verticals and bracing	10 ,,	,,
Ribands	15 ,,	,,
Handrail, &c.	5 ,,	,,
Total	180 ,,	,,

Thus p may be taken as 180.

On the other hand, the weight of infantry in fours is taken as

$$560 \text{ lbs.} + 50 \text{ per cent.}$$

$$= 840 \text{ lbs. per foot run.}$$

Then maximum tension in lower members is

$$\frac{(180 + 840)\, 100^2}{16 \times 12{\cdot}5} \sqrt{1 + \left(\frac{75}{100}\right)^2}$$

$$= 63{,}699 \text{ lbs.}$$

$$= 29 \text{ tons nearly.}$$

And maximum tension in upper member is

$$\frac{100^2}{16 \times 12{\cdot}5} \left\{ 180 + 840 \times 1{\cdot}5 \right\} \sqrt{1 + \left(\frac{25}{100}\right)^2}$$

$$= 74{,}088 \text{ lbs.}$$

$$= 33 \text{ tons practically.}$$

This latter figure will therefore decide the size of the cables.

Each upper member will have to stand half of this or 16·5 tons, and taking the safe stress in steel wire rope as 9 C^2 cwt., the necessary size of rope is found to be 6 inches.

The maximum horizontal component of the stress in the diagonal bracing is

$$\tfrac{1}{2} \times \frac{840 \times 100^2}{16 \times 12{\cdot}5} \left(\frac{20}{100 + 20}\right)$$

$$= 3{,}500 \text{ lbs.}$$

The direct stresses in the various diagonals and verticals can be best determined graphically. Referring to Pl. LIV., Fig. 4, and choosing a scale for the stresses, such that the length representing

10 feet, the breadth of the panel, shall also represent 3,500 lbs., it will be found that the direct stresses are as follows :—

Diagonals.

JN	3,714 lbs.
KM	4,183 ,,
MT	3,717 ,,
NS	4,599 ,,
SY	3,553 ,,
TX	4,592 ,,

Verticals.

JK ...	1,400 lbs.	Length ...	4 feet.
MN ...	2,100 ,,	,, ...	6 ,,
ST ...	2,100 ,,	,, ...	6 ,,
XY ...	1,400 ,,	,, ...	4 ,,

Using round spars of Baltic fir, and allowing 2,000 lbs. per square inch safe stress in tension, and 1,500 lbs. per square inch compression, it will be seen that spars of 2 inches diameter are required for all the diagonals, spars of 3 inches diameter for the verticals JK and XY, and of 4 inches diameter for MN and ST.

To calculate the length of the slings, their length from the horizontal line through C is given by the formula

$$y=\frac{8\times 12\cdot 5}{100^2}x^2-\frac{2\times 12\cdot 5}{100}x,$$

and giving x the successive values of 40, 30, 20, and 10, these lengths are found to be

1st sling	+6 feet.
2nd ,, ...	+1 foot 6 inches.
3rd ,, ...	−1 foot.
4th ,, ...	−1 foot 6 inches.

To make the length of the shortest slings about 3 feet, an allowance of 4 feet 6 inches will have to be added to each of these values, and there is also the camber of the roadway to be allowed for. If the roadway has a parabolic camber, with a rise of 16/0 of the span at the centre, the allowances to be made are found from the formula

$$y=\frac{4\times \frac{100}{60}}{100^2}x^2,$$

x being measured as before. Substituting the values of x, these allowances are found to be

1st sling	+1 foot $0\frac{3}{4}$ inch.
2nd ,, ...	$+7\frac{1}{4}$ inches.
3rd ,, ...	$+3\frac{1}{4}$,,
4th ,, ...	$+\ \frac{3}{4}$,,

and the length of the slings is as set forth in the following table :—

Distance from abutment.	Number of sling.	Length to horizontal through C.	Length of central sling.	Camber allowance.	Total.
10′	1st	+ 6′	+ 4′ 6″	+ 1′ 0¾″	= 11′ 6¾″
20′	2nd	+ 1′ 6″	+ 4′ 6″	+ 7¼″	= 6′ 7¼″
30′	3rd	− 1′	+ 4′ 6″	+ 3¼″	= 3′ 9¼″
40′	4th	− 1′ 6″	+ 4′ 6″	+ ¾″	= 3′ 0¾″
50′	5th		+ 4′ 6″		= 4′ 6″

The height of the piers is

$$12' \, 6'' + 4' \, 6'' + 1' \, 8'' = 18' \, 8''.$$

As a useful check on the accuracy of the calculations to determine the length of the slings, and the height of the piers, it may be noted that their extremities lie on curves of the second degree, and therefore, as they are at constant distance apart, their second differences must be equal, as follows :—

		1st difference.	2nd difference.
Piers	18′ 8″		
		+ 7′ 1¼″	
1st sling	11′ 6¾″		+ 2′ 1¾″
		+ 4′ 11½″	
2nd „	6′ 7¼″		+ 2′ 1½″
		+ 2′ 10″	
3rd „	3′ 9¼″		+ 2′ 1½″
		+ 8½″	
4th „	3′ 0¾″		+ 2′ 1¾″
		− 1′ 5¼″	
5th „	4′ 6″		

All the other calculations necessary can be worked out in the usual way.

The disadvantage of this form of bridge is that a wide level area is required on which to make up the cable girders. The practical difficulties of forming the girders while the cables hang across the gap would be very great.

Single-ended suspension bridge.

35. Single-ended suspension bridges often form a satisfactory method of crossing gaps between steeply sloping banks. They should be calculated as if they were half of a bridge of twice the span having piers of equal height. If there is an unloaded portion of cable at either or both ends the equivalent span for use with the formulæ, para. **5**, can be found by the graphic method given in para. **39**. They are built as a combination of a common and a ramp suspension bridge. (Pl. LIII., Fig. 1.) The anchorages of such a bridge require careful design to ensure that there is sufficient earth in front of the anchor log; while the transom over which the cable is led must be very firmly seated. In such a type it may often happen that the portion of the cable near the higher anchorage will be unloaded, causing the loaded portion to sag more than was anticipated.

Single central pier.

36. A single central pier is another application of the suspension bridge and has the advantage that less anchor power is necessary and only one pier has to be constructed. The stresses in the cables are those at the highest and lowest points of a complete span of double the half-span. (Pl. LI., Fig. 6.) Suspension bridges for light traffic may be composed of a roadway suspended from a single cable. The slings of the transoms being separated to give the requisite width and headroom by means of spreaders. Such bridges are, however, very liable to lateral sway and require to be well guyed. The road-bearers of such a bridge should cross as many transoms as possible. Pl. LIII., Figs. 3 and 4, shows the method of use of the spreaders. The piers are most easily formed of sheer legs, but a cross-piece of timber should be added above the crutch to prevent the cable biting into the lashing of the sheers.

Trestle suspension bridge.

37. A simple application of the trestle suspension bridge to a narrow gap is illustrated in Pl. LIII., Fig. 2. It would be a suitable type to adopt over a deep ravine of no great width. The central support is composed of a four-legged trestle slid out along the cables to the centre of the span.

38. In India, thick ropes of creepers are suspended, two above and one below, Pl. LII., Fig. 3, and fastened at intervals to forked branches. A man can cross by walking on the bottom cable and holding the upper two. Other creeper bridges have been constructed of a tubular form, the creepers thus forming the suspension cables and the handrail at the same time.

In the absence of better means a single cable can be applied to carry heavy loads across a chasm as shown in Pl. LII., Fig. 7. When the load is heavy compared to the cable the latter will form two nearly straight lines and the maximum stress (*i.e.*, with the load at the centre) can be got directly. But with a heavy cable the formula for a concentrated load (para. **5**) must be used. A block or traveller is required to sling the load which is dragged across by a hauling rope. (Ropeways, para. **40**.)

39. The following is a graphic method of investigating the stresses in a suspension cable when on one or both sides of the bridge there are unloaded lengths of cable strained over piers of possibly different heights, or attached to anchorages at different levels.

Pl. LIV., Fig. 5, is a diagrammatic representation of such a bridge. In it A and B are the anchorages on either side of the tops of the piers over which the cables are strained. C D is the gap to be bridged. The portion E F of the cable vertically above C D is the loaded portion and hangs in a parabola. O P represents the vertical axis of this parabola. The unloaded portions of the cable, viz., A E and F B, will be straight and will be tangential to the parabola at E and F. M N is the tangent at the vertex and is, of course, horizontal. It is required to find the heights of the points E and F and the position of the axis O P.

The construction is as follows (Fig. 6) :—

Let C D represent the gap and A and B the positions of the anchorages or tops of the towers. Draw the horizontal line M N to represent the tangent at the vertex. As for a given span the maximum tension in the cable increases as the dip decreases, it is desirable to keep this tangent as low as possible. Its position will in any case be determined by the camber desired in the roadway of the bridge plus an amount required for the shortest sling, due allowance being made for any difference in the level of the abutments.

Erect verticals C R and D S at C and D to cut M N in R and S.

Bisect R S in Y.

Join A R and B Y and produce them to meet at G.

Join A Y and produce it to meet B S produced in H.

Join G H and let G H cut a vertical through Y in X.

Join A X and B X and let them cut M N in T and V respectively. Lay off along M N, T O equal to R T. Then O is the vertex of the parabola.

The accuracy of the construction can now be checked by measuring O V, which should be equal to V S.

Points E and F in A X and B X vertically above C and D will be the tangent points on the parabola.

If the tangent at the vertex is on the same level as B, X will coincide with Y and O with S, and consequently these points can be immediately found.

To find the dip of the parabola, draw a horizontal line E K cutting O P in K.

Then twice E K will be the equivalent span and K O will be the dip.

These points E and F are equivalent to the tops of piers at the corresponding heights and the formula, para. **5**, can be applied.

The greatest tension will, of course, occur at E or F, whichever is the higher.

Aerial ropeways.

Aerial ropeways.

40. Ropeways are useful in a fortress for the distribution of ammunition, stores and water, or on a line of communication or for handling material in the reconstruction of large bridges. Wind is the chief source of interruption in working ropeways.

Two systems in use.

41. The two main systems of ropeways are :—

(1) Fixed rope system.
(2) Running rope system.

In the former, a fixed cable carries the load and acts as a supporting rail. In the latter, the cable supports the load and provides the motive power as well.

The advantages of the fixed rope system are :—

(1) The supports for the main cable are simpler.
(2) The gear required to move the hauling rope is not so cumbrous as that required for the running rope system.

The fixed rope system is therefore more suitable for use in the field in improvised installations.

The factors which decide the type of ropeway suitable to any given situation are as follows :— Deciding factors.

(1) The character of the ground over which it has to be erected.
(2) The class of material to be transported and the manner in which it adapts itself to the suggested loads.
(3) The grades of the inclines it has to surmount.
(4) The length of spans between supports.
(5) The total amount of work required.
(6) The motive power available.
(7) The carriage of loads in both directions, and the different nature of these loads.

42. The fixed rope system may be of either of the following designs :— The fixed rope system.

(1) A single fixed rope which acts as a rail, upon which a single carrier is hung—The carrier is pulled along the fixed rope in either direction by means of an endless rope called a "hauler." The "hauler" is moved by any suitable form of driving gear which must be capable of reversing.

The standards which support the fixed rope are fitted with pulleys to carry the hauling rope.

This design is only suitable for dealing with single heavy loads. It has been worked successfully under the following conditions :—Load 5 tons. Maximum slope of ropeway 1 in 1. Maximum span between standards, 100 yards.

(2) Two parallel fixed ropes act as rails on which the carriers run out on one and back on the other, drawn by means of a suitable hauler.

This design may be used where a large number of loads up to 6 cwt. are dealt with.

It has been worked successfully under the following conditions :—Load 6 cwt. Maximum slope of ropeway 1 in 2. Maximum span between supports 200 yards.

It is economical in wear and tear but is unsuitable where the slopes change abruptly.

The two fixed ropes are set about 7 feet apart and are supported on standards. These ropes are anchored at one terminal station, while at the other a straining gear is introduced in order that the stretch of the rope may be taken up. The carriers run on the fixed ropes and are transferred from one to the other by means of a shunt rail. In this system the hauler is run at speeds between 4 and 6 miles an hour. The attachment of the hauler to the carrier must be designed so that the hauler may be released from the carrier at the moment the latter runs on to the shunt rail.

(3) Two parallel fixed ropes each supporting one carrier. The hauler connects these two carriers, which move out and in, each on its own rope. Such an installation is suitable to extremely long spans with heavy loads (up to 5 tons). It is peculiarly suitable for situations where the ropeway may be actuated by gravity, when the loaded carrier pulls up the empty or less heavily loaded carrier on the other rope. With this arrangement, ropeways have been run at speeds up to 30 miles an hour. Such installations are controlled normally by a brake drum at the upper terminal; the brakesman should be able to see the lower terminal. If the loads have to be moved up the incline, driving gear must be introduced and is best placed at the upper terminal. By this method speeds up to 10 miles per hour have been attained.

(4) A modification of the fixed rope system, but which is suitable only to special circumstances, is that generally called a "shoot." This form consists of a single fixed rope on an incline and on this rope carriers are allowed to run down one at a time and uncontrolled by brakes. The system is very simple but it is only suitable for transporting goods which cannot be damaged. The loads are usually limited to 1 to 4 cwt., and some form of buffer is introduced to absorb the momentum of the descending carrier. Brushwood is often used for this purpose. The sag of the rope should be adjusted so that the speed of the carrier is reduced by an up gradient near the lower terminal. The carriers are as light as possible and are collected at the lower terminal—the empties being hauled to the top of the line as opportunity occurs.

Running rope system.

43. The running rope system consists of an endless running rope which combines both duties of rail and hauler.

This system may be divided into two classes :—

(1) In which the carriers are permanently fixed to the rope and therefore must move with it.

(2) In which the carriers are actuated by automatic grips of some form which permit the release of the carrier from the rope.

In class (1) the operations of loading and unloading must be performed while the carrier is in motion, for the stoppage on one carrier stops the whole system. In class (2) carriers may be run on to a shunt rail to be loaded. Both these forms require a combined driving and tension gear.

Class (1) is suitable in those situations where the gradients are very steep or change abruptly. Owing to the carriers having to follow the rope special mountings for the terminal driving wheels must be made which will permit the carriers to follow the rope round the circumference of each wheel. This form of terminal necessitates light loads. Again, the loads being always moving must be handled rapidly. No greater speed than 2 to $2\frac{1}{2}$ miles per hour can be secured with this system, and at these speeds special arrangements have to be made to allow of loading.

Pl. LV., Figs. 1 and 2 show the usual form of attachment and type of terminal.

Class (2) is suitable for gradients not exceeding 1 in 3. The loads may be 6 cwt. and the space between supports 200 yards. A driving and straining gear is required for all running rope systems of ropeways, and a shunt rail is also required to transfer the carriers from one side of the terminal wheel to the other.

Carriers.

44. Carriers may be of any form suitable to the material which is to be handled; several simple forms are illustrated in Pls. LV. and LVI. Carriers.

The wheel base of the carrier carriage should be short.

In order to prevent the carriage from tipping vertically when ascending a gradient the rod connecting the carrier frame to the carriage must be pivoted to the saddle so that the rod may always hang vertically.

To prevent it tipping laterally, the suspended rod must be so bent that the centre of gravity of the load is vertically below the cable. The standards must be so designed that no projections on them will foul the carrier. In a high wind the carriers and their loads tend to sway laterally and to strike the standards. The ropeway cannot be worked under such conditions. The attachment of the carrier to the hauling rope or cable is an important feature and each system requires special consideration to meet its particular requirements.

45. In the fixed rope systems, the carriage to which the carrier is attached consists simply of either a single or a pair of suitably grooved wheels (Pl. LVI., Figs. 1 and 3). Below this carriage and attached to the frame of the carrier is a device which forms the connection between the carrier and the hauler. This connection is secured either by friction plates which clip the rope between them—or by a system of pawls which engage on a thickened portioned of the rope. It is termed either a (1) friction or (2) locking grip. Grips.

46. In order that the ropeway may be worked at an efficient speed the design of the grip must be simple, automatic, and such as to cause a minimum of wear and tear to the rope. Friction grip.

With ropeways installed on the moving rope pattern, but in which the carriers are not rigidly fixed to the rope, another system of grip must be employed. The most usual form consists of a saddle of Λ section, which rests on the moving rope. This shape of saddle permits the carrier to follow the rope over supporting pulleys and it is usually provided with wings which embrace the pulley and prevent any tendency of the saddle to jump the rope at these points. The Λ-shaped saddle is fitted with friction blocks, generally of malleable iron, though wood blocks are sometimes used, in order that tbe requisite amount of friction may be set up. In order that this grip may be automatically released, the frame carrying the saddle is fitted with two small wheels carried on axle pins. These are termed the shunt wheels, and are intended to engage on the shunt rail, which is slightly inclined upwards for the first yard. As the shunt wheels run up the shunt rail the saddle is lifted clear of the rope, and the carrier is free to be run to any desired position on the shunt rail for purposes of unloading and loading. (Pl. LVI., Fig. 2.) The rope, usually travelling at about 4 miles per hour, ensures that each carrier has sufficient momentum to enable the carrier to clear itself from the rope. Tbese friction grips are not reliable on gradients steeper than 1 in 3, and then only with loads not exceeding 6 cwts. Friction grips are liable to slip in wet weather. A great advantage of the frictional grip is that the wear and tear on the rope is distributed along its length, since the carriers engage at different points on the cable or hauling rope. In moving ropeways they bave great advantages over rigid attachments for carriers, since they allow the number of carriers to be increased or decreased as desired. If it is desired to increase the output it is found to be more economical to increase the number of carriers, while the rope maintains its original speed.

Locking grip.

47. Locking grips depend for their efficiency on the introduction of some thickening or swelling in the hauler. These swellings are termed knots. They are formed either by introducing a piece of steel into the core of the rope or by fitting a sleeve on the outside of the rope.

Star knot.

48. The best known of tbese is termed the star knot (Pl. LX., Fig. 1). It consists of a steel cylinder provided on its outside surface with the same number of spiral grooves as there are strands in the rope corresponding with the lay of the rope. The diameter of the cylinder is rather larger than that of the rope on which it is to be employed. The rope is untwisted at the proper place and a portion of the core removed. The cylinder is placed in the centre of the rope and the strands are laid in the grooves on its outside. The rope is then twisted up taut. For the sake of strength the rope is often untwisted so far as to allow about a fathom of the hemp core being removed and replaced by a wire strand of equal size, a hole being bored axially through the cylinder to permit of the substituted wire being passed through.

The new core is then wedged with steel wedges where it passes through the cylinder and the rope again twisted taut as before. There are several other forms of knot on the same principle, but their methods of attachment vary, some being soldered to the rope with white metal.

49. A simple type of this grip (Pl. LVI., Figs. 3, 4, 5 and 6) is composed of a frame carrying two corresponding and similarly mounted pawls. Each is movable vertically, and is provided with a forked end of such size as to pass the rope but engage on a knot. The pawls are prevented from falling below their normal position by a stop, and are fitted at their upper end with pins and projections by means of which the pawls may be raised clear of the rope if suitable means are provided. The frame carries a grooved pulley immediately below the pawls, which forms a support for the hauler, and which revolves with the rope when the pawls are out of action. **Pawl grip.**

The action of the grip is as follows :—

The carrier having been moved on to the cable, the hauling rope moves in the grooved pulley. On the arrival of a knot, the first pawl is engaged from behind, and, owing to its shape, is lifted clear, and the knot then engages on the face of the second pawl. The first pawl then drops back on the rope behind the knot, and would engage the knot should the direction of movement of the rope be reversed. Thus the grip is effective in either direction of movement of the rope.

The automatic release of the grip is effected as follows :—

A second and lighter rail is supported below, and parallel to the switch rail. The ends are bent downwards so as to engage below the projections or pins of the pawls mentioned above, and, forming a gradual ramp upwards, raise the pawls clear of the knot. The height of the releasing rail must correspond to the position of the pins when the pawls are raised to clearing height. A similar ramp at the other end of the rail permits the pawls to again fall into their working position. The rails which release the pawls should project about 1 yard in front of the shunt rail, so that the rope may be released the moment the carrier arrives on the shunt. The momentum of the carrier serves to carry it well on to the rail. The pawls being raised and the supporting pulley having no groove or flange is withdrawn from under the hauler. The fork of the pawl guides the rope until a knot engages it. In order to avoid unnecessary jar the carriers should be pushed off the switch rail when it is desired that they should return to the cable, so that they may be already in motion when the knot engages with the pawl. Loads of 1 ton and upwards may be safely hauled on gradients of 45° by means of these pawl grips.

Terminal stations.

50. The terminal stations of a ropeway provide the anchorage and driving gear, and means for loading and unloading. In the **Terminal stations.**

majority of cases the latter are provided by means of a switch rail. (Pl. LV., Fig. 1 and LVII., Fig. 1.) It consists simply of a rail of length, plan, and shape suitable to requirements, mounted on supports which allow the passage of the carriers round the terminal to the return cable.

When the carriers are rigidly attached to the moving cable in order that they may be loaded on the move, a secondary rail is introduced above the cable, on which trucks may move a short distance with and above the carrier, and from these trucks the carriers are loaded by means of a hopper.

With all moving rope systems, the terminals must provide the power and the means of working the cable. With detachable carriers this is not difficult, since the rope may be led round any required number of pulleys. But with fixed carriers the carrier must follow the course of the rope. This introduces difficulties in applying the power. Pl. LV., Fig. 2, shows a carrier actually passing the circumference of the wheel. One of the essentials of the driving gear of a ropeway is that it must be possible to adjust the tension of the cable as desired and to correct for the elongation of the cable in use. With the fixed rope systems the main cables are usually solidly anchored at one end and strained as required from the other by means of weights or a windlass. The usual method is to employ a hanging weight to produce the required tension. This keeps the tension in the cable constant, and permits the rope to sag if the tension increases above the working point, and thus adjust itself to the load. (Pl. LVII., Figs. 2 and 3.) Whenever possible the tension gear should be installed at the lower terminal of a ropeway, since in this position less weight may be employed to produce a given tension in the rope. The tension weight may either be installed in a pit or the cable may be led over a pulley placed at the top of a tower. The introduction of a tackle, as shown in Fig. 2, forms a ready means of correcting the position of the weight, which would otherwise be displaced by the stretching of the cable. A shallow pit only will therefore suffice. Stations with tautening gear may be introduced at intermediate points of an installation where it is impossible to avoid an angle. They are connected together by switch rails as at a terminal station. These intermediate stations often form a more economical means of changing direction than a long curve, which must be supported by very heavy standards. Junctions between several converging ropeways may be made by means of switch rails. The actual drum of the driving gear varies in pattern, but usually a whole turn of the cable is taken round it and the drum is provided witb grooves to lead the rope: special arrangements being introduced to prevent the tendency of the rope to climb the drum and jam. This is effected by the introduction of independent idle pulleys, the cable passing alternately round the driving drum and the pulleys. In moving rope installations, whenever possible, the power should be applied to the loaded rope.

In selecting sites for the terminal stations, it must be remembered that they have to resist the whole tension in the cable, and must be rigidly constructed. Any unnecessary addition to their height adds to the difficulty and expense of construction.

They must therefore be as near the ground level as possible.

Standards.

51. In any system of ropeways the rope must be suitably supported at intervals by means of standards. These may be of either iron or wood, and the intervals between them will vary according to the conformation of the ground. All standards must be truly in the line of the ropeway; any deviation from the line will prevent the rope running true and will entail greatly increased wear on both pulleys and rope. In moving rope installations the heights of the standards must be such that the level of the point of support of the rope rises above the line representing the catenary of the rope both when fully loaded and unloaded. If this is not the case, the rope will jump from the pulleys. With fixed rope systems this is not so important, for arrangements may be introduced to guide the rope back to its bearing. Pl. LVIII., Fig. 1 shows the loaded carrier passing the support and raising one of the guides as it passes. The guide falls back at once into position, after the carrier has passed, ready to guide the cable as it rises. In all installations the height of the standards must be such as will allow the carriers to clear all obstacles when the rope is loaded to the utmost. Standards.

The simplest form of standard consists of round spars forming the legs while the supports for the rope are carried on selected timber cross-pieces. The legs should be let into the ground to a sufficient depth to ensure stability. In the case of steel standards the structure should be securely bolted to concrete foundations. The best method is as follows:—A wooden template is constructed with holes corresponding exactly to the holes pierced in the feet of the trestle to receive the holding-down bolts. The template is supported exactly on the centre line and at the same height as the feet of the trestle are to be when finally fixed. (Pl. LVII., Fig. 4). The holding-down bolts are suspended through the holes in the template and the concrete foundation is filled in round them, leaving a few inches clearance round the bolts. Holding plates are provided at the bottom of the bolts to ensure that they shall be able to effectually resist any tension likely to come on to them when the trestle is set up. The trestle is then set up and the play of the bolts in the spaces left in the concrete allows of the final exact adjustment of its position. All standards should be stayed with iron guys if above 50 feet in height.

Various forms of trestle are shown in Pls. LVIII. and LIX.

52. The actual points of support vary according to whether a fixed or running rope is employed. A fixed carrying rope is usually supported at the standards in either iron saddles, seatings, shoes, or cradles designed so that no resistance is offered to the Methods of supporting cables at standards.

passage of the wheels of the carriers. An easily improvised support for a fixed rope is shown in Pl. LVII., Figs. 5 and 6. The hauler is supported by its attachment to the carriers, but if the interval between these is considerable, rollers are provided on the standards, which are provided with brackets or arms to receive them. The method of supporting the cable is a matter of great importance, for owing to variations in temperature and in the positions of the loads, the carrying cables move over their supports a short distance, and if they become rigidly attached the standard may be overturned. The cable is therefore often carried on grooved sheaves, but owing to the small bearing surface, a very great amount of friction and consequent wear in the rope is set up. Sometimes the cable is carried in a saddle, which itself moves on rollers running on racers, but these often jam at the end of their path. A more satisfactory method is by the attachment of the rope to the end of pendulum arms permitted to swing through the necessary angles and provided with quadrant guides to prevent any sideways movement.

With moving ropes some form of revolving pulley is essential, and in order that these may have a sufficient bearing surface, and to reduce wear, multiple pulleys are introduced. The most successful method has been a design known as the balancing sheave. The idea of the design and construction is shown in Pl. LIX., Figs. 3 and 4. The pulleys are mounted in pairs on secondary arms, so that the whole support may adapt itself to the rope. This arrangement is found to reduce the wear and tear of the rope, and is capable of withstanding great thrusts, thus permitting very long spans. The fact that the arms allow the pulleys to adapt themselves to the rope permits the pressure of it to be evenly distributed among the pulleys. These bearing pulleys are made in sizes, 18, 21, and 24 inches in diameter, and are intended to take thrusts of 500, 750, and 1,000 lbs. each respectively. They are mounted in pairs, and used in sets of 2, 4, and 6.

Description of cables to be used.

53. The ropes used in the installation of ropeways differ somewhat in their characteristics, but it is found that ropes of Albert lay (ropes in which the wires composing the strands are laid up at the same angle as the strands) are the best for wear. The ropes for fixed ropeways may have wire cores, as when once laid out in position, stiffness has not any great disadvantages. For moving ropeways, the rope must be flexible, and for this reason, ropes with hempen cores are used. The ends of these ropes are connected by means of long splices. Six-strand ropes are therefore most suitable, for with them a very level splice can be formed free from any thickening or projections, which would very shortly become worn. In these ropes the strands are the same size as the core, and can be substituted for the latter when a portion of it has been removed, which ensures a level splice.

Laying out the cable.

54. The laying out of the cable of a ropeway often presents great difficulties. The method usually adopted is to unreel the cable and form it into small coils with a length of slack between.

These small coils are then placed on the backs of pack animals, the size of the coils and the distance apart being dependent on the strength of the animal. In spite of every precaution, the irregular progress of the animals will cause a number of kinks in the rope.

55. A kink in wire rope may be successfully removed by placing two clamps on the rope, one on either side of the kink, leaving just room between to use a mallet. Then, if the kink is unbent in the direction in which it is formed, while at the same time the rope is twisted into proper form by means of the clamps, it will be possible to set down the wire into proper shape with the mallet. A wooden mallet should be used in preference to a hammer, as it does not cut or notch the wires. **Kinks.**

56. Lubrication is essential for moving ropes; a very considerable portion of the wear is caused by wires and strands working against one another and producing a sort of cutting action. An oiled rope may be worked over from twice to five times more bends than one that is not oiled. Any lubricant employed must be of such a kind as will thoroughly permeate the rope and act not only between the rope and the pulleys, but also between the wires composing the strands. It must also resist the action of sun and rain. Plain linseed oil, and black West Virginia oil fed on to the rope by automatic lubricators are both satisfactory. Virginia oil is the most successful lubricant for ropeways, and it has given excellent results when fed into the ropeway at the rate of 1½ gallons per month per mile of rope. Plain linseed oil may also be used. For the protection of fixed ropes, the following mixture, applied while hot, has given beneficial results as a protection from the weather and against rust:—Six parts tar, two parts linseed oil, and two parts tallow. **Lubrication.**

57. The pulleys and drums round which wire ropes are worked should have a diameter at least equal to six times the circumference of the rope. If a smaller diameter is used, the outer strands and wires of the rope get unduly strained. For high speeds a greater diameter than the above should be used. **Size of pulleys and drums.**

In order to secure the cables to the anchorages, eyes are usually formed in the cable end to which shackles, &c., may be attached. (Pl. LX., Fig. 2.) "A" is a thimble of suitable size, according to the rule given above, round which the cable is passed; the end and the standing portion of the cable are then clamped securely together by U-shaped clamps and plates. This is the simplest and quickest method of forming an eye. "C" is a form of split tapered sheath ending in an eye. The rope end is placed in the sheath and rings are then shrunk on the sheath. Before being placed in the sheath the rope end is formed to a conical shape by unravelling a short portion and turning back the wires in layers, each layer being bound with wire. Successive layers are shortened and in turn bound down so that the resulting end **Fixing cables to anchorages.**

can be brought to the desired shape. "D" represents another split socket, into which the conical end of the rope is introduced, rivets being driven through the whole. In the case of "E," which is a convenient ending to a rope in situations when it is intended to use bolts for connecting on, the rope-end is passed completely through the cylindrical portion of the fitting and formed into a conical end as before. The interior of the cylinder is coned to receive it, and the rope is then drawn back into the fitting.

Survey of ropeway.

58. The survey for a ropeway must be carefully executed, and when the direction of the installation has been decided, the centre line should be accurately pegged out with a theodolite. An accurate section of the ground should then be made on a large scale and the depth of solid ground at those points where it is proposed to erect the supporting standards should be ascertained. It is important that, wherever possible, the ropeway should be in a straight line, as each angle renders necessary the introduction of an angle station into the installation. An angle station increases both the first cost of construction and maintenance of the line. These angle stations very generally consist of a complete station similar to those at the terminals, connected by rails, on which the carriers may pass from one portion of the installation to the other.

If the line includes a high hill with concave slopes, the gradient of the rope can only be reduced over this concave section either by using very high trestles or by using long spans. The latter is the more usual method. This question of gradient is particularly important if a moving rope system is proposed. But it must be borne in mind that a long span causes a greater dip in the rope, and this may itself cause too steep a gradient. This can be taken up by increased tension in the rope, but it should be remembered that by increasing the tension a larger rope may be necessitated, and this larger rope in turn will require heavier trestles and supporting pulleys, larger and stronger terminal installations and pulleys, and heavier tension weights. These increase the initial cost of the line very greatly, and it will often be more economical to revert to a fixed rope system.

Example.

59. As an example of a ropeway, suppose that a line is required to deliver 10 tons an hour in individual loads of $1\frac{1}{2}$ cwt., *i.e.*, 1 shell for 6″ howitzer (122 lbs.) or 1 man.

This means $\frac{10 \times 20 \times 2}{3}$ loads per hour,

or loads at ·45 minute intervals.

One of the moving rope systems will therefore seem suitable. If the fixed carrier is adopted a greater speed than 2 miles an hour will not be admissible, but gradients up to 1 in 3 are allowable.

If the rope moves at 2 miles per hour, in ·45 minutes the carrier will move $\frac{2 \times 1,760}{60} \times \cdot 45 = 25\cdot 9$ yards.

The loads must therefore be 26 yards apart.

Suppose now that the installation contains a span whose difference in level at the standards, which are 300 yards apart, is 120 feet.

Consider the rope as uniformly loaded and that the rope weighs 10 lbs. per fathom, then we have as the weight per 26 yards

$$\frac{3}{2} \times 112 + 10 \times 13 = 130 + 168,$$
$$= 498 \text{ lbs. per 26 yards,}$$
$$= \text{say 20 lbs. per yard.}$$

When the trestles are level we have as the steepest gradient from Sec. XI., para. 5, $\tan \theta = \frac{4d}{a}$,

and the tension of the lowest point $= \frac{wa^2}{8d}$.

But the greatest gradient must not exceed 1 in 3,

$$\therefore \tan \theta = \frac{1}{3} = \frac{4d}{a},$$

$$\text{or } d = \frac{a}{12},$$

and the greatest tension becomes $\dfrac{wa^2}{\dfrac{8a}{12}}$,

$$= \frac{3}{2} wa.$$

In our case the trestles are not level and a must be taken as the span of the parabola in which our rope hangs between our highest trestle and an imaginary point level with our highest trestle. (Pl. LX., Fig 3)

That is $a = 410$ yards.

Using this value for a we find our tension at the bottom of the

$$\text{sag} = \frac{3}{2} \times 20 \times 410 \text{ lbs.,}$$
$$= 12{,}300 \text{ lbs.,}$$
$$= 5 \text{ tons.}$$

At the upper trestle there is an increase of tension due to the weight of the line itself. We must know this tension in order to find the thrust on the bearing pulleys at the standard.

The tension at the highest point is given by the formula (para. 5)—

$$T = w\frac{a}{2} \sqrt{1 + \left(\frac{a}{4d}\right)^2}$$

In our case $w = 20$ $\qquad a = 410.$

$$d = \frac{a}{12} \qquad \therefore \frac{a}{4d} = 3.$$

$$\text{Substituting, tension} = 20 \times 205 \sqrt{1 + (3)^2}$$
$$= 13{,}120 \text{ lbs.,}$$
$$\text{or } T = 5{\cdot}75 \text{ tons approx.}$$

Suppose that the span in question AB has next above it a span of BC of 150 feet.

Then the thrust on the standard B is equal to $\frac{1}{2}$ wt. of span AB + $\frac{1}{2}$ wt. of span BC + T tan ϕ, where ϕ is the angle made by the line CB produced and AB. (Pl. LX., Fig. 4.)
In this case the thrust on B

$$= \tfrac{1}{2}(300 + 50) \times 20 + T \tan \phi$$
$$= 3{,}500 + 13{,}000 \tan \phi \text{ lbs.}$$

Suppose that we mean to employ four bearing pulleys of the type shown in Pl. LIX., Fig. 4, each pulley being designed to carry 1,000 lbs. Then the thrust must not be greater than 4,000 lbs.

That is :—

13,000 tan ϕ must not be greater than 4,000—3,500 = 500,

or tan ϕ must not be greater tban $\frac{500}{13{,}000} = \frac{1}{26}$,

or the angle ϕ must not be greater than $\tan^{-1} \frac{1}{26}$.

If the section of the ground does not permit of this a change must be made in the proposed support, or even the whole arrangement of the line must be revised and new positions for the trestles selected.

SECTION XII —FRAME AND TENSION BRIDGES.

Frame bridges.

General observations. 1. Frame bridges, composed of two frames resting on the sides of a gap and locking into one another, are used to provide intermediate points of support for the road transoms when the latter cannot be supported directly from the bottom. They are, in fact, substitutes for an arch. The length of the intervals between the transoms depends on the strength of the road-bearers, while tbe width across the gap at the footings of the frames and the depth of the latter below the surface decide the number of transoms to be used, and consequently the form of the bridge.

The forms of bridge suitable are :—

For 1 transom or 2 bays ... Single lock (Pl. LXI., Fig. 1).
" 3 " 4 " ... Single sling (Pls. LXII. and LXIII.).
" 5 " 6 " ... Treble sling (Pl. LXIII.).

If the width at top to be bridged is much wider than the width between footings, trestles or other means may be employed to bridge the additional distances between the footings and the banks. (Pl. LXI., Fig. 1.)

The slope of the frames should not be flatter than ½.

2. When there is any choice as to the site of the bridge it is desirable, if possible, to select one where the *span between the footings* will be the same at each side of the bridge. The footings should also be on the same level at each end of the bridge. Site of bridge.

3. If men cannot cross from bank to bank, a communication must be made between them. A packthread line may be thrown by hand across an opening up to 150 feet wide by laying it out as in Pl. LXI., Fig. 2; or a tracing line can be thrown across a gap of 120 yards by means of a 1 lb. signal rocket. Other lines can then be hauled over. Or a single spar can be passed across, as in Fig. 3, or, instead of the sheers, an ordinary frame, Fig. 4 (whose transom must be towards the bank from which the frame is launched), can be made to support two or more spars, which may be connected by light transoms. By keeping its feet steady and letting the frame incline outwards, the spars are carried across the gap. When these are got over, light planks can be at once laid on them, thus forming a bridge in a few minutes. A pair of baulks may also be passed over by using two wheels and an axle. (Fig. 5.) Making communication between the banks.

4. Before the bridge can be commenced, the probable positions for the footings should be chosen. They should, if possible, be exactly opposite to one another, and all four footings should be on the same level. Laying out section of gap.

A section of the gap should then be laid out on the ground, full size, with tape and pickets. Successful locking of the bridge will depend on the accuracy of this section.

If the width of the chasm on either side of the bridge is not the same, or if the footings are not on the same level, two sections must be taken, one for each side; and both should be laid out on the same piece of ground. It can then be seen whether the footings can be levelled by excavating, or whether the frames will have to be unsymmetrical.

5. To allow for the stretching of rope lashings and slings, the roadway should have a *camber* of $\frac{1}{60}$th of the length of the bridge, *i.e.*, having stretched a tape (on the section) from one shore transom to the other, the centre of the tape should be raised by $\frac{1}{60}$th of its length, and it will then represent the roadway. Camber

The distance between the footings, as shown on the section, is then divided equally to agree with the number of road transoms, and *vertical* lines raised from these points till they meet the tape representing the roadway. If the slope of either of the frames is flatter than ½, the position of the road transoms or footings must be shifted till that slope of ½ is arrived at. As soon, however, as it is certain that the spars available and other conditions will allow of the positions chosen for the road transoms, these positions should be marked by pickets on the tape representing the roadway.

Marking the spars.

6. The frames are constructed in a similar manner to trestles, except that their transoms are on the *shore* side of the frames and the ledgers away from it, and that the legs slope so that the butts are 2 feet further apart than the tips. The marking of the spars is, therefore, the next step to take when the type of bridge to be erected (para. **1**) has been decided. The road transoms should be represented on the section by pieces of spar, or circles drawn on the ground; and the legs should be laid on the section, and the positions of the *frame* transoms and ledgers marked on them with chalk, as described in Sec. X, para. **6**. When the frames are unsymmetrical, the two legs on one side of the bridge should be marked first and the other two afterwards, the transoms remaining on the section all the time.

When one frame has to lock inside the other (Pl. LXII., Fig. 1), the latter is made 18 inches wider throughout than the former. The distance between the marks on the road transom and ledger of the narrow frame should be 18 inches greater than the clear width of the roadway.

Besides the lashing marks on the road transom, their centres must also be marked. The legs, having been marked, are laid out with their butts towards the gap, and with the transom underneath and the ledger generally on the top of them.

The legs are then moved about till they are at the proper distance apart, and the ledgers and frame transoms marked; and the whole are lashed and squared as described for two-legged trestles (Sec. X., para. **6**), 2-inch rope being used for the transom lashings, which must be very carefully made.

Position of ledgers.

7. When the site is rocky, the ledgers should not touch the ground and should therefore be a foot or two from the butts. On soft soil, however, the ledgers should be near the butts, and a second one, or a plank under the feet, may, if required, be added to prevent settlement. In this case the ledgers must be nearly as stout as the transoms.

Railway materials.

8. Railway rails may be used for all parts of frame bridges (Pl. LXII., Figs. 2 and 3), except the legs of sling bridges, for which they are not long nor strong enough. They are, moreover, liable to slip through their lashings, and on that account light poles or planks should be obtained if possible, for diagonals. Sleepers are most easily lashed to the flat-bottomed section (Fig, 2); to lash them to double-headed rails, a block of timber (Fig. 3) is required so as to prevent the rail turning in the lashings; when lashed on the flat, these rails buckle with slight weight. The transoms must project sufficiently beyond the rails to prevent the lashings from falling off; the latter may be tightened by keys or wedges.

Footings.

9. In all bridges where the butts of the spars require footings made for them, these should be so formed that the spars may be easily lowered vertically into them, and their bottoms should be in a plane perpendicular to the direction which the spars are to take.

10. Holdfasts are required for guys and foot-ropes. (Part IIIA, Sec. V., para. **13**.) Holdfasts.

11. The roadway of frame bridges is laid as described for trestle bridges (Part IIIA. Sec. II). Where the ends of the road-bearers meet and overlap one another they must be lashed together in two places, or adzed, so as to prevent their pushing the chesses up, which they would otherwise do on account of the camber. Roadway.

The operation of laying the roadway may be carried on simultaneously from both sides, if stores for that purpose be previously in position. In this way the roadway for a bridge 50 feet long can be laid by 16 men in from half an hour to an hour, including passing across the road-bearers and lashing them down.

Single lock bridge.

12. A single lock bridge is composed of two frames locking into each other, forming two bays, as shown in Pl. LXI., Fig. 1. The road-bearers rest on a road transom placed in the forks made by the legs, and generally called the "fork transom." This bridge is suitable for spans (between footings) not exceeding about 30 feet, and can be erected by two or three non-commissioned officers and 20 men in about an hour, if the stores are in their proper places on each bank, and if the footings are easy to make. The working party may be increased to about 30 men with advantage. If the footings have to be cut in masonry an hour or more should be allowed for preparing them. Single lock bridge.

While the frames are being marked and lashed as already described (paras. **5** and **6**), the footings for the butts of the frames can be prepared, and holdfasts made for the foot and guy ropes; the holdfasts for the former should be about 4 paces from the bank and about 4 paces on each side of the central line; those for the guy ropes about 20 paces from the bank and about 10 paces on each side of the central line. The foot ropes are secured by timber hitches to the butts of the frames, the fore and back guys by clove hitches to the tips, and the fore guys passed across to the opposite side. The guys of the narrow frame should be inside the guys and legs of the wide frame. Construction.

When all is ready the frames are got into position, either one after the other, or both at the same time, if there be sufficient men. One man is told off to each foot rope, and one to each back guy to slack off as required, two turns being taken with each of these ropes round their respective holdfasts. The other numbers raise the frame and launch it forward, being assisted by the men manning the fore guys on the other side of the gap until the frame is balanced on the edge of the bank; the butts must then be gradually lowered into the footings prepared for them, by slacking off the foot ropes, the head of the frame hauled over till beyond the perpendicular, and lowered nearly into its ultimate position by slacking off the back guys, the men on the fore guys assisting to guide it. It can be kept in this position by making fast the guys to their holdfasts, until the other frame has been treated in a similar manner. The two frames are then gradually lowered by means of the back guys, and guided by the fore guys until the legs of the narrow one rest on the transom of the other between its legs; both frames are then lowered until they lock, their legs resting on each other's transoms. The operations thus far described should not occupy more than 45 minutes.

Modified lock bridges.

13. When the spans exceed 30 feet additional points of supports may be provided, as in Pl. LXII., Fig. 4.

Fig. 5 shows iron fastenings instead of lashings.

Single sling bridge.

Single sling bridge.

14. A single sling bridge (Pl. LXII., Fig. 1) consists of two frames locking above the roadway as in a single lock bridge; and provides three points of support for the road-bearers, viz., one road transom lashed half-way up each frame, and one suspended by slings from the fork transoms, thus forming four bays. It can be used for spans (between footings) up to 50 feet, and takes about 30 to 50 men about 4 hours to make.

Construction.

15. In marking the spars the frame transoms are first placed on the section not less than 9 feet above the roadway (Part IIIA. Sec. II, para. 5), and when the frames have been lashed a single 8-inch snatch-block, with falls rove and secured, should be hooked to a selvagee at each of the tips of the legs of the narrow frame on its under side.

The frames are then launched, narrow one first, and got into position as in the single lock bridge, or by means of sheers, if necessary. A couple of road-bearers are now got out to the road transoms, and two men climb to the top to assist in getting into position the fork transom D, which is raised by means of the blocks attached to the tips of the legs; one end is raised first and slewed into its fork beyond its final position, and hauled back again when the other end has been got opposite its fork.

Meanwhile the slings may be made as follows:—Two groups of pickets are driven at the proper distance apart to represent the fork and road transom and a 3-inch rope wound round them four or five times, avoiding riding. Spun yarn is then used to lash their ends and to secure the returns, at intervals, in position. They are eventually passed up by the block and tackle.

Spanish windlass sling.

The suspended transom B is then, by means of the blocks, got into position a little above that it will finally occupy, and supported by ropes. If the slings have not been made beforehand they are placed as follows:—A 3-inch rope (one of the guy ropes) is sent up to the top on each side, passed over the three transoms, down underneath the suspended one, up again round the top ones, and so on until there are four parts or more supporting the lower one, and the ends are then secured together.

Care must be taken that the suspended transom bears equally on each bight of rope, and also that the ropes do not ride over one another. When the road-bearers have been laid the thick end of a handspike is inserted in the space between the ropes passing up, and those passing downwards, and by turning the handle round them several times with the thick end as a centre, the ropes may be twisted and tightened up to the desired extent, until the transom is raised sufficiently. The handle of the handspike must be secured to one of the legs of the frames, or to a road-bearer, by a lashing, and great care must be taken that it be not let go in the operation of twisting.

It has been found from experiment that a Spanish windlass sling twisted three complete turns is about one-eighth weaker than if untwisted.

The operation of getting the frames into position will require about three hours. Extra time should be allowed if the footings have to be cut in masonry or brickwork.

16. In order to give the legs more support at the points of loading A and C, it is desirable to have long outer road-bearers continuous from A to C, and to lash them at these points to the legs; or, better still, if spars of sufficient length can be obtained, the legs can be strutted at A and C, as shown dotted. The loads at A and C are thus supported by the resistance to crushing of A G and A E, and of C E and C G, instead of the cross-breaking resistance of the leg. To prevent buckling, the struts should be lashed together where they cross, and it is advisable to add a cross-piece, F. Struts.

Stiffened single sling bridge.

17. A stiffened single sling bridge (Pl. LXIII., Fig. 1) is an ordinary single sling bridge in which the cross-breaking stress on the legs is relieved by rope or chain ties, which pass from the road transom over vertical frames on the banks to anchorages. It may be used for spans (between footings) up to 60 feet wide, and made in the same time as an ordinary single sling bridge, if the working party be increased by about 20 men. Stiffened single sling bridge.

18. The main frames should be put up as before, except that the ties B A and B C are fastened round the standards and transoms at A and C, and are thus carried out with the frames. Construction.

The vertical frames (Pl. LXII., Figs. 6 and 7) should be the same width at top as the bridge frames nearest to them at the road transom in order to facilitate keeping the ties straight. Their legs may be vertical as Fig. 6, or inclined as Fig. 7. It is advisable to put side struts to steady them as in Fig. 6. The height of the transoms should be such that the ties passing over them will be nearly at right angles to the legs. This will be the case if the height of its transom is about the same as that of the fork transoms. These frames may be made at the same time as the main frames, and to the right or left of them, and when the latter are up they should be cross-lifted into position for raising, and the ties should be laid across their transoms while they are on the ground. If a bank slopes the vertical frame may take the place of the trestle, which would otherwise be required. (Pl. LXIII., Fig. 1.)

Ties and anchorages.

19. The ties are secured to anchors, each consisting of a large log buried in the ground (Part IIIA., Sec. V.)

With logs as here used, a mean depth of 2 feet to 2 feet 6 inches will be enough. The excavations should not take longer than 1½ to 2 hours, and when time presses, they should be carried out simultaneously with the making of the frames.

The distance of the anchorages should be such that the ties will make equal angles on each side of the vertical frames. The latter are raised by fore and back guys and foot-ropes. The ties are then hauled taut and secured to the anchorages, and racked up if necessary. In working with chain, if no coupling-irons or other means be at hand, it can be tightened by a stick, which must be introduced into a loop before the chain is taut. This racking no doubt strains a chain unevenly. With double chains the Spanish windlass can be used, and is better,

The ties are then lashed to the top transoms (B, B, Fig. 1), after which the fore guys may be removed and the back guys are secured at the bollards D. These bollards are about 30 feet apart, one on each side of the roadway.

Stiffened treble sling bridge.

Stiffened treble sling bridge.

20. The stiffened treble sling bridge (Pl. LXIII., Fig. 2), only differs from the last in having each leg tied at two points instead of one, which allows the span to be divided into six parts. It may be used for spans (between footings) up to 70 feet, and from 36 to 48 men should make it in 6 to 10 hours if the materials be all at hand.

Construction.

21. The construction of this bridge differs from that of a stiffened single sling bridge in the following points:—The frames are braced by diagonals both below and above the roadway. The vertical frames should be similar to those of the single sling bridge. The distance of the anchorage should be such that the angle of the ties on one side of the vertical frame shall be about equal to the mean of the angles made on the other side.

The upper ties are fastened to the legs at H before launching the frames. The latter, if made with light or composite spars, are kept nearly vertical till the vertical frames have been raised and the upper ties passed round the anchorages; and the ties are slacked out slowly while the frames are being lowered, so as to support them at H. The ties are then lashed to the transoms J, J, and the slack of the back parts taken in till the vertical frames lean a little over away from the gap.

A couple of road-bearers are then got out on to the first road transom, and the remaining road transoms are slung as in the single sling bridges. At the same time the lower ties are taken out, secured to the main legs at their junction with the road transoms, and passed up over the transoms J and back to the anchorages, where they are secured, the slack being taken in by racking up, either in front or in rear of the vertical frames. These ties also should be lashed to the transoms of the vertical frames.

22. With crowded fours the pull at a slope of about $\frac{1}{1 \cdot 5}$ will be about 15,000 lbs. dead load on each anchorage. (Part IIIA., Sec. V., para. **16**, and Pl. XXXV.) **Anchorage.**

Stiffened sling bridges with more than three slings can be made, if spars long enough for the legs can be obtained; and as the legs are subjected to little or no cross-breaking stress, they need not be remarkably stout. Thus 80 feet can be spanned as shown in Pl. LXV., Fig. 3, if legs about 56 feet long and 12 inches in diameter at the centre are available. If the footings are made on a level with the roadway, as shown, derricks or sheers will have to be used to raise the frames.

23. The following tables show the spars, tools, and materials required for building the bridges illustrated in Pls. LXI., LXII., and LXIII. **Stores required.**

The *minimum* diameters and lengths of the spars are shown. The diameters are calculated for infantry in fours, and best selected dry timber with modulus of rupture about 12,000 and factor of safety for cross-breaking 2, and for crushing 5. When using ordinary unselected timber the **diameters should be increased by one-half.**

In most cases the lengths of the spars may be increased by 1 or 2 feet with advantage.

Numbers and minimum sizes of SPARS required for making Frame Bridges.

For unselected timber the diameter should be increased by half.

Nature of bridge, and span between footings.	Single Lock. 30 ft.			Single Sling. 50 ft.			Stiffened Single Sling. 60 ft.			Stiffened Treble Sling. 70 ft.		
Spars and Planks required.	Number.	Diam.	Length.	Number.	Diam.	Length.	Number.	Diam.	Length.	Number.	Diam.	Length.
2 MAIN FRAMES.												
		in.	ft.		in.	ft.		in.	ft.		in.	ft.
Legs ... ...*centre*	4	$7\frac{1}{2}^{a}$	20	4	$9\frac{1}{2}^{a}$	37	4	6^{a}	41	4	9^{a}	50
Transoms ... ... *thro'*	2	5	15	} 3	$5\frac{1}{2}$	14	3	6	14	3	6	14
Ledgers ... ... *thro'*	2	4	15	2	4	15	2	4	15	2	4	15
Diagonals ... ... *thro'*	4	3	20	4	3	20	4	3	20	8	3	20
Distance pieces ... *thro'*	0	...		} 0	...		0	...		0	...	
1 SHORT VERTICAL FRAME.												
Legs ... ...*centre*	...	...		...	...		2	$4\frac{1}{2}$	15^{g}	2^{d} 4^{e}	8 $6\frac{1}{2}$	24 24
Transom ... ... *thro'*	...	...		...	...		1	6	12	1	6	12
Ledger ... ... *thro'*	...	...		...	...		1	5	15	1	5	15
Diagonals ... ... *thro'*	...	...		...	...		2	3	15	2	3	17
1 LONG VERTICAL FRAME.												
Legs ... ...*centre*	...	...		...	...		2^{d} 4^{e}	7^{h} 6^{h}	24 24	2^{d} 4^{e}	$9\frac{1}{2}^{h}$ 8^{h}	33 33
Transom ... ... *thro'*	...	...		...	...		1	6	12	1	6	12
Ledger ... ... *thro'*	...	...		...	...		1	4	13	1	4	13
Diagonals ... ... *thro'*	...	...		...	...		2 2	3 3	15 13	} 4	3	17
MISCELLANEOUS.												
Road and fork transoms } *thro'*	1	$8\frac{1}{2}$	15	} 3	8	14	3	$8\frac{1}{2}$	14	5	$7\frac{1}{2}$	14
Shore transoms ... *thro'*	2^{k}	6	15	2^{k}	6	15	2^{k}	6	15	2^{k}	6	15
Road-bearers † ...*centre*	10	$5\frac{1}{2}$	18	10^{d} 20^{e}	5^{m} 5	28 15	10^{d} 20^{e}	$5\frac{1}{2}^{m}$ $5\frac{1}{2}$	33 18	10^{d} 10 30^{e}	5^{m} 5 5	28 14 14
Ribands † ... ... *tip*	4	3	18	4^{d} 8^{e}	3 3	28 15	4^{d} 8^{e}	3 3	33 18	4^{d} 4 12^{e}	3 3 3	28 14 14
Hand-rails, if of wood † ...	80	feet run		120	feet run		130	feet run		150	feet run	
Hand-rail supports ...	6	3	5	4	3	5	0	...		0	...	
Planks, 10′ × 12″ × 2″[n] † ...	34	...		54	...		64	...		74	...	
Racks for slings and ties }	0	...		2	3	6	6	3	6	14	3	6
Anchorages (firm loam) ...	0	...		0	...		2^{d} 6^{e}	12 6	14 14	2^{d} 6^{e}	12 6	17 17

[a] Not less than 5 inches at tip.
[b] If there are only two distance pieces.
[c] If there are more than two distance pieces.
[d e f] are alternatives.
[g] 12 feet if braced with side guys.
[h] If the road-bearers are firmly lashed at both ends, diameters may be the same as for the short vertical frame.
[k] Not needed if abutments are level and hard.
[m] *Throughout*, not *centre*.
[n] $1\frac{1}{2}$ inch thick if pontoon chesses are used.

* For these bridges the vertical frames are two-legged trestles (paras. 101 to 109).

† The numbers must be increased if the sides of the gap are not vertical.

Number and sizes of Ropes required for making Frame Bridges.

Nature of bridge and span between footings.		Single Lock. 30 ft.		Single Sling. 50 ft.		Stiffened. Single Sling. 60 ft.		Stiffened Treble Sling. 70 ft.	
Rope required for	Circumference inches.	Number.	Length, fathoms.	Number.	Length, fathoms.	Number.	Length, fathoms.	Number.	Length, fathoms.
2 Main Frames.									
Ties	*	...	...	...	...	4	12	8	12
Guys	3″	8	20–28	8	26–33	8	30–36	8	35–40
Foot-ropes	3″	4	9	4	9	4	9	4	9
Transoms	2″	4	6	4, 4	8, 6	8	6	4, 4	8, 6
Ledgers	1½″	4	6	4	8	4	6	4	8
Diagonals	1½″	4	6	8	6	...	...	4	6
Diagonals	1½″	4	6	...	6	8	6	12	6
Road-bearers ...	1″	0–10		10–30		10–30		20–50	
Diagonals	1½″	2	6	2	6	2	6	4	6
Miscellaneous q ...	1″	20		18		28		36	
Rack-lashings ...	...	16	...	32	...	40	...	40	...
Slings	3″	...	...	2	20–30	2	20–30	6	20–40
Falls	2″	...	...	2	20	2	20	2	20
1 Short Vertical Frame.									
Transoms	2″	...	...	...	...	2	6	2	8
Ledgers	1½″	...	...	...	...	2	6	2	8
Diagonals	1½″	...	...	...	...	4	6	4	6
Diagonals	1½″	...	...	...	...	1	6	1	6
Miscellaneous q ...	1″	...	...	...	...	2		2–8r	
1 Long Vertical Frame.									
Transoms	2″	...	...	...	...	4	6	4	8
Ledgers	1½″	...	...	...	...	2	6	2	8
Diagonals	1½″	...	...	...	...	8	6	8	6
Road-bearers	1″	...	...	...	...	4–10	6	4–10	6
Diagonals	1½″	...	...	...	...	2	6	2	6
Miscellaneous ...	1″	...	...	...	...	2–8r		2–8r	
Rack-lashings ...	...	...	...	...	...	8	...	6	...

* Safe strength of each to be 2½ tons.

q Including handrail supports and wooden handrail.

r Eight if each leg consists of two spars lashed in three places.

Tools and Materials required for making Frame Bridges.

Nature of bridge and span between footings. / Tools and miscellaneous stores.	Single Lock. 30 ft.	Single Sling. 50 ft.	Stiffened Single Sling. 60 ft.	Stiffened Treble Sling. 70 ft.
Axes, felling	1	1	1	1
Axes, hand†	1	1	1	1
Axes, pick	4	4	4	4
Bars, crow, 4 ft.*	4	4	4	4
Blocks, snatch, 8-in.	2	2	6	6
Chalk, pieces	2	2	4	4
Chisels, masons'*	4	4	4	4
Hammers, masons'*	4	4	4	4
Handspikes, common	2	6	6	6
Levels, field service	1	1	1	1
Lines, tracing, 150 ft.	1	1	1	1
Mauls	2	2	2	2
Pickets, tracing, bundles	2	2	2	2
Posts, picket, 5-ft.	8	8	8	18
Posts, picket, $2\frac{1}{2}$-ft.	4	4	4	8
Rack lashings	...	...	...	...
Rods, measuring, 6 ft.	2	2	2	2
Selvagees, 4-ft.	...	2	6	6
Saws with sets and files, cross-cut	1	1	1	1
Saws with sets and files, hand	1	1	1	1
Shovels †	4	4	4	4
Tackle, luff, 3-in. rope	...	...	...	1
Tapes, measuring, 100-ft.	2	2	2	2
Tapes, tracing, 50 yds.	2	2	4	4
Yarn, spun ... lbs.	7	7	7	7

* Not wanted unless footings are in masonry.
† Three less if footings are in masonry.

Tension bridges.

Tension bridges.

24. When the span exceeds 60 or 70 feet, or when the legs required for frame bridges cannot be procured, tension bridges may be found suitable. (Pl. LXIV.)

Some of the advantages of these bridges over frame bridges are—

1st. They are suitable for larger spans.
2nd. The ties are more easily transported than timber.

The roadway is as rigid as that of a frame bridge, but they require more adjustment and take longer to make.

The method of determining graphically the stresses in ties and struts is explained in Part IIIa., Sec. III., para. **17**.

Understrutted tension bridge.

Understrutted tension bridge.

25. The understrutted tension bridge (Pl. LXIV., Fig. 1) is designed for a span of 100 feet and a roadway 6 feet wide in the clear, but is equally suitable for smaller spans; thus, if the ties T_2 on each side of the centre be omitted, it would be suitable for a span of 78 feet, while if both T_1 and T_2 be omitted the span becomes 56 feet. The loads on all the transoms, except that at the centre, are carried by the tension of a pair of ties and the compression of a pair of struts. The load on the central transom is carried by two pairs of ties (T_1). In order to prevent undue stress in the ties, the height of the piers should not be less (and may be more) than one-fourth the span for both forms of tension bridge.

Construction.

26. To construct the bridge, the section is marked out, and the positions of the road transoms decided upon, as well as those of the two vertical frames. The excavations for the anchorages are traced, and the diggers distributed. The vertical frames may be made as shown in Figs. 1 and 2, where each leg is stiffened by a post inserted below the transoms, and lashed at several points to the leg. The post should butt against the transom and extend to the extreme foot of the leg. The lashings should be tightened up by wedges. Composite spars may also be used as legs; they are more easily lashed and wedged, and can be made to give better support to the transom if two spars of each leg are made to butt against it. An 8-inch snatch block is lashed outside the tip of each leg, which should be 2 or 3 feet above the transom; each block has a 3-inch rope rove through it, and passed through a snatch block secured to each leg 3 feet above the ground.

Raising frames.

27. The first frame is raised in the same way as sheers; the back struts (Fig. 1) being lashed loosely to the tips of the frame while on the ground (butts to the rear) and being used in raising them. Foot-ropes are also required. When the frame is vertical (or slightly inclined from the gap), the butts of the back struts are bedded in the ground and the back guys are made fast. The side struts (A, A, Fig. 2) are then raised by the falls, their feet bedded in the ground and their tips lashed to the tops of the frames. The fore guys are then cast off, and the back guys replaced by wire rope if possible.

The second frame is then raised and secured in a similar manner, but its fore guys are led through the blocks at the tips of the standards of the first frame.

Both frames should now slightly incline away from the gap, as the subsequent operations will tend to pull them forward.

Placing under-struts.

28. The four falls are now free for use. The outer pair of road struts (C_1) on either side are laid between the legs of the vertical frames with the tips at the edge. A transom D is lashed across and above the tips, which are 7 feet 6 inches apart in the clear, while the butts, when in place, should be 9 feet apart in the clear. Foot-ropes are tied to the struts, and the running ends of the falls of the opposite frame are tied to the transom, and those on their own side to the struts near their tips. The ties T_2 are now secured round the struts and the transom (if of wire rope, by a complete turn and with seized ends). The falls of the frame upon the opposite side are then hauled upon to carry out the struts. Their feet are let into the footings. The falls of the frame on the near side are then hauled on till the transoms are slightly above their proper position. The ties are then made as taut as possible and their land ends secured. The tackles are then cast off. Light poles (E, F) are used to connect the struts and prevent lateral bending; these poles may be lashed on as the struts go out. The inner struts are got out in the same way and the road-bearers laid down. The chesses are then laid. To keep the struts from bending downwards they may be hung up to the transoms at one or more points (as at E, F) by rope, or, better still, may be connected together by light poles, which, if long enough, can also support the handrail. Lastly, the ties T_1 are secured to the central transom and got into place; the ends being anchored with the others and the slack taken in.

The central bays are then completed and high ribands or baulks are racked down at a clear interval of 6 inches more than the wheel track.

When the ties have been lashed to the frame transoms at B, the back guys of the frames may be removed. Steadying guys should be brought from the ends of the central road transoms, crossed under the roadway, and brought to the bank, where they should be hauled taut and secured well to the right and left of the bridge to prevent oscillation sideways.

Anchorages.

29. In loam, the anchorages may consist of one large or three smaller buried logs, the excavations being at such a distance to the rear as will make the total thrust down the pier vertical, as in Fig. 1.

Time required.

30. This bridge could be made by two non-commissioned officers and 40 men in from 24 to 30 hours, all stores and materials being at hand.

Tension bridge with struts.

Tension bridge with struts.

31. The form of bridge given in Pl. LXIV., Fig. 3, may be used when spars long enough for understruts cannot be obtained; the bridge illustrated is arranged for 80 feet, but by varying the number of the ties it may be used for larger or smaller spans. The loads, except that on the central transom, are supported by the ties and by the resistance to compression of the outer road-bearers, which here take the place of struts, and should, therefore, have a less load, in proportion to their size, to carry as road-bearers. In earth, the thrust of these road-bearers should be taken as in Fig. 4; with rock or masonry, footings for the butts of the road-bearers can be cut instead.

Mode of construction.

32. The mode of construction of this tension bridge is somewhat similar to that for an understrutted one (para. **25**). With earthen banks, the feet of the piers below the ledgers are let into the ground and a second ledger laid against them, sheeting being provided to distribute the pressure (Fig. 4).

The outer road-bearers, which should be each in one piece long enough to extend beyond M, (Fig. 3), a renow got out as described in para. **28**, but with the transoms M, N on the under sides and at the proper distances, the intervals between these outer road-bearers being 6 feet 6 inches in the clear. As each transom leaves the bank, its ties are secured round it, outside the outer road-bearers, the feet of which have a sill dogged to them, which bears against the feet of the standards. The outer road-bearers may be composite spars if long timbers are not available.

The ties are now made taut, so as to give more slope than $\frac{1}{20}$, which should afterwards be the permanent amount, and, as before, the ties are secured to the pier transoms by lashings.

The roadway is now made out to the transoms M, and the ties for the central transom placed, fixed up, and secured to the same anchorages as the others. The transoms M M, on each side of the centre should now be connected by lashings to the central one. These lashings should be strong and capable of being racked up; when taut, if the bridge be fully loaded, they lessen the compression in the outside road-bearers.

Anchorages.

33. The stress in the back ties being nearly the same in this case as in the last, the same anchorages may be used (para. **29**).

Time, men, &c.

34. This bridge, like the other, should have steadying guys, and might be constructed at about the same rate and with the same number of men.

Tension bridge without struts.

Tension bridge without struts.

35. Pl. LXV., Fig. 1, shows a tension bridge without struts. In this form each transom is supported by two pairs of ties, each pair passing over a pier to an anchorage. Each tie may, if desired, be given a separate anchorage, and this has the advantage that the failure of an anchor affects only one transom. The individual anchorages do not have to resist so great a tension and are therefore more easily constructed, and their construction can proceed simultaneously. Individual anchorages are most suitable when only a shallow stratum of earth overlies a stratum of rock; or where holes have to be jumped in rock for iron bar anchorages (Part IIIA., Pl. XXXIV.). Each tie can be made to make equal angles at the pier, thus ensuring a vertical thrust, and these can be more easily adjusted when each has its own anchorage.

In long spans the lighter ties are more easily handled and placed across the gap than the heavy cables required for a suspension bridge, but a greater length of cable is required. Wire ties may be made up as described in Part IIIA., Sec. IV., para. **30**.

The bays of a tension bridge should be the longest possible with the road-bearers available, so that the weight of the superstructure may keep the ties straight. If the superstructural load on the ties is small the ties hang in a curve and only straighten under the traffic load. This makes the adjustment of the bridge difficult. For this reason, if heavy ties are to be used it is often desirable to use trussed beams (Sec. IX.) as the road-bearers.

In order that the ties may pass each other without fouling, they should be reversed in order on each pier. Thus, in Pl. LXV., Fig. 2, the ties of each transom are outside on one pier and inside on the other.

If many ties have to be handled it will often save confusion if the ends of the transoms are coloured and the positions of the ties are marked on the capsills of the piers with corresponding colours.

Modified tension bridge.

36. In Pl. LXV., Fig. 4, is given the outline of a tension bridge with one central pier, which is guyed to both banks, so as to provide against unequal loading on the bridge. The inward thrust of the road-bearers must in this case be provided for at the pier.

Stores required.

37. The tools and miscellaneous stores required for making a tension bridge are the same as those required for a stiffened treble sling bridge (para. **20**), with the addition of four pickaxes and four shovels (for digging anchorages), two 8-inch snatch blocks, two selvagees, and 7 lbs. spun-yarn. For the 80-feet tension bridge, eight ⅝-inch iron dogs are useful.

The following table of spars and ropes is calculated for infantry in file, or carriages weighing not more than 30 cwts. on the heavier pair of wheels. The *minimum* diameters and lengths of spars are given, the diameters being calculated for best selected dry timber with a modulus of rupture of about 12,000, and a factor of safety of, for cross-breaking, 2, for crushing, 5. When using ordinary unselected timber **the diameters should be increased by one-half.**

In most cases the lengths of the spars may be increased by 1 or 2 feet with advantage.

Numbers and minimum sizes of Spars and Ropes required for making Tension Bridges.

For unselected timber the diameters should be increased by half.

Nature of bridge and span between footings.	Strutted Tension Bridge. 100 ft.			Unstrutted Tension Bridge. 80 ft.			Remarks.
Spars required.	No.	Diam.	Length.	No.	Diam.	Length.	
		in.	ft.		in.	ft.	
Struts C_1 ... *centre*	4	$8\frac{1}{2}$[a]	45	...	...	...	[a] 5 in. is enough if thoroughly cross-braced every 15ft.
Struts C_2 ... *centre*	4	7[a]	33	...	...	...	
Struts C_3 ... *centre*	4	$4\frac{1}{2}$	18	...	...	...	
Road transoms *thro'*	7	7	9	5	7	9	
Road-bearers— 5 in. in diameter at 6 ft. from either end.	B 10	...	17	B 10	...	17	Either B or B_1 *and* either C, C_1, or C_2.
	B 10	...	15	B 10	...	12	
	B_1 10	...	30	B_1 10	...	27	
	C 10	...	24	C 20	...	17	
	C_1 20	...	13	...	...	...	
	C_2 5	...	24	...	...	...	
	C_2 10	...	13	...	...	...	
Ribands	Same size as road-bearers, and two-fifths as many.						
Handrail and supports and for racking ties, &c.	350 feet run			200 feet run			3 in. diameter.
Frame transoms *thro'*	2	7	12	2	7	12	E if legs are single spars.
Frame legs ... *centre*	E 4	$9\frac{1}{2}$	28	E 4	7	23	E_1 if 3 spars to each leg.
	E_1 12	6	28	E_1 12	5	23	
Frame ledgers *thro'*	2	8	14	6	7	14	
Frame struts ... *centre*	8	5	32	8	5	28	
Diagonals ... *centre*	4	4	18	4	4	18	
Anchorages (firm loam)	F	12	14	F 2	12	14	F or F_1, buried 3 ft. deep.
	F_1 6	8	14	F_1 6	8	14	
Chesses	G 75	$12 \times 1\frac{1}{2}$	10	G 60	$12 \times 1\frac{1}{2}$	10	G if laid askew.
	G_1 104	$12 \times 1\frac{1}{2}$	$7\frac{1}{2}$	G_1 84	$12 \times 1\frac{1}{2}$	$7\frac{1}{2}$	G_1 if laid straight
Cordage required.	No.	Circumference.	Length	No.	Circumference.	Length	
		tons.[h]	fathoms.		tons.[h]	fathoms.	
Ties T_1 Ropes or Chains	2	1·6[h]	38	2	2[h]	34	[h] These are the necessary safe strengths in tons.
Ties T_2 Ropes or Chains	4	1·6[h]	18	4	$2\frac{1}{4}$[h]	15	
Ties T_3 Ropes or Chains	4	1·6[h]	17	4	$1\frac{3}{4}$[h]	14	
Ties T_4 Ropes or Chains	4	1·6[h]	16	...	...	...	
		in.	fathoms.		in.	fathoms.	
Guys	4	3	35	4	3	30	
Falls	4			4			
Footropes	4	3	6	4	3	6	
Frame transoms ...	4	2	8	4	2	8	
Frame ledgers ...	4			4			
Road transoms ...	14	2	6	10	2	6	
Frame struts ...	12	$1\frac{1}{2}$	6	12	$1\frac{1}{2}$	6	
Road-bearers... ...	28-50	1	6	25			
Braces E, F, &c. ...	12			0	...	...	
Diagonals	8			8	1	6	
Diagonals	2	1	$3\frac{1}{2}$	2	1	$3\frac{1}{2}$	
Handrails, &c. ...	40			20			
Holdfasts	16			16			

Section XIII.—RAILWAY BRIDGES.*

Construction.

Railway bridging.

1. Railway bridging for military purposes will most likely be required in connection with the repair of a line damaged by the enemy. In some cases it will be possible to repair damaged bridges; otherwise new bridges must be constructed. The type of bridge suitable for such replacement will also serve for hasty bridges on a new line.

The material generally available is timber. Complicated construction and all mortice and tenon work should be avoided, the parts as far as possible being made to "butt square."

Fastenings as a rule will consist of dogs, drift-bolts, bolts and nuts, spikes and fish-plates. It is advisable to make provision for a number of hardwood packing pieces about 12″ × 6″ varying in thickness from ½″ to 3″. These are required to be fixed as necessary under rail-bearers to adjust their level. This arrangement is quicker than sawing out recesses on rail-bearers where they rest on capsills.

Gradients and curves should be avoided on hasty railway bridges, and, if possible, the approaches should be straight and level portions of line.

The type of bridge almost universally employed is the simple or trussed beam supported on trestles, crib-piers or piles.

Economy of time is usually the great desideratum in military bridging. When therefore an obstacle on a line of railway has to be bridged, it is necessary to decide whether it will be quicker to make the bridge at the original level of the railway or to make a deviation and cross the obstacle at a lower level.

High level v. deviation.

In arriving at a decision, the following points must be considered :—

(i) The materials available.

(ii) Whether the features of the ground permit the construction of deviations.

(iii) The amount and nature of labour that will be available.

(iv) Whether the bridge at the original level will necessitate so much time being spent on it before it is fit for traffic that it will more than counterbalance the loss of time inevitable in the use of a deviation (owing to sharp curves and steep gradients). A high-level bridge requires more skilled labour than a low-level one. The possibility of a deviation on either side of the original line must also be considered in this connection.

(v) The possibility of the débris of the original bridge blocking the way for the erection of another in the old alignment.

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* This subject is more fully dealt with in Military Engineering, Part VI., Military Railways.

(vi) The possible alteration of the ruling grade by the building of low-level deviations necessitating such reductions in engine loads that the capacity of the line would fall below requirements owing to shortage of engine power.

In many cases deviations necessitate the provision of a banking engine, meaning extra locomotives, or the splitting of the trains, both of which entail delay as well as the provision of sidings, for which points are often not available.

The restoration of railway communication frequently resolves itself into three stages :— **Stages of construction.**

(i) Construction of deviation and bridge at low level.
(ii) Construction of semi-permanent bridge at original level.
(iii) Reconstruction of permanent bridge.

The last stage is really outside the scope of hasty military bridging, and will only be touched on here incidentally.

Details of Bridge.

2. The track is supported on longitudinal beams, simple or trussed, termed rail-bearers. The weight of the locomotive and the dimensions of the available material will determine the length of the bays and the number of rail-bearers. In the case of timber bridges the spans of simple beams should not usually exceed 20 feet, or 35 feet in the case of trussed beams. **Rail-bearers.**

In calculating the size and number of rail-bearers it is usually assumed that the locomotive brings a distributed load on the bridge, the amount depending upon the span and the axle loads. By this means the difficulty of ascertaining the maximum bending moment due to several moving loads on a beam is eliminated. In cases where a large amount of railway bridging work has to be done, it is desirable to calculate at once the equivalent distributed load from the actual axle loads of the heaviest locomotive for the various spans likely to be used (Part IIIA., Section III.), and from these to compile a table of suitable sizes for rail-bearers (Part IIIA., Section IV.). This will do away with the necessity of calculations in the field. The calculations should be based on the loads derived from two of the heaviest locomotives coupled together, at the head of the train. In view of the moderate speeds not exceeding 25 miles an hour at which trains must necessarily run over a repaired line, an allowance of 50 per cent., for impact, will suffice for hasty military bridges. In timber bridges the weight of the superstructure may be neglected ; and a factor of safety of 3 should be allowed. With the allowance for impact this gives a total factor of safety of 4½. **Calculation of rail-bearers.**

The following table, giving the numbers and sizes of rail-bearers of Baltic fir, has been worked out from the average equivalent distributed loads imposed by three British main line locomotives of an average heavy class (Pl. LXVI.) on certain spans of single track.

Span in feet.	Tons per foot of *Single Track.*	bd^3.	5″ × 9″	10″ × 10″	12″ × 12″	14″ × 14″	9″ × 18″	15″ × 15″	16″ × 16″	18″ × 18″	20″ × 20″
			405	1,000	1,728	2,744	2,916	3,375	4,096	5,832	8,000
5	$6\frac{3}{4}$	2,570	6	2	—	—	—	—	—	—	—
$7\frac{1}{2}$	$4\frac{1}{2}$	3,855	—	4	2	—	—	—	—	—	—
10	4	6,048	—	—	—	—	2	2	—	—	—
12	$3\frac{3}{4}$	8,164	—	—	—	—	—	—	2	—	—
14	$3\frac{1}{2}$	10,584	—	—	6	4	4	—	—	2	—
15	$3\frac{1}{4}$	11,340	—	—	8	—	4	—	—	2	—
16	3	12,096	—	—	8	—	4	4	—	2	—
18	$2\frac{7}{8}$	14,154	—	—	8	—	6	—	4	—	2
20	$2\frac{3}{4}$	16,632	—	—	—	6	6	—	4	—	2
25	$2\frac{1}{2}$	23,625	—	—	—	—	8	—	—	4	—

An allowance of 50 per cent. has been made for impact, and a further factor of safety of 3 for the timber, making a total factor of safety of $4\frac{1}{2}$. The intensity of stress in the timber (Baltic fir) does not thus exceed 2,000 lbs. per sq. in.

Unless loads much in excess of those shown in the diagrams of engines have to be legislated for, the following rule of thumb may be used on an emergency :—

> "For 20-ft. span use a 20″ by 20″ timber under each rail.
>
> "For each reduction of a foot in span reduce each side of the timber by $\frac{1}{2}$″."

With the further proviso that the speed at which the trains run is duly restricted, this rule is applicable to the metre, 3′ 6″, and 4′ $8\frac{1}{2}$″ gauges, for the conditions of timber and factors of safety indicated above.

It is unlikely that timber of such section as to admit of only using 2 baulks per span will always be available: but it will only be necessary, when such baulks are not available, or are not considered desirable, to ascertain the cube of the figure given by the above rule of thumb, in order to obtain the value of bd^2 for the road-bearers which must be used under each rail.

It may be noted that timbers above 16 inches by 16 inches are not often obtainable, and in any case are heavy and troublesome to work with.

Grouping and fixing rail-bearers.

When more than one rail-bearer has to be used under each rail they may be grouped as shown on Pl. LXVII., Figs. 1–5. Here it will be observed that the rails are placed either vertically above or slightly inside the centre of the rail-bearers. At least every third sleeper should be spiked or bolted to the rail-bearers. All the rail-bearers under each rail must be securely bolted together and *fixed to the top member of the point of support*. This is best done by drift-bolts.

If the length of the available material permits, rail-bearers should extend over two bays and break joint. Rail-bearers which butt must be fastened together. A rough method of doing this is to use a dog or fish-plate as shown on Fig. 6, but a much better method is to use cover-plates, as shown on Fig. 7. The bolts should be placed as in the figure.

When the rail-bearers butt care must be taken that the ends have sufficient bearing surface on the point of support. A length of 6 inches of bearing surface for rail-bearers on the point of support is just sufficient provided the ends are well tied together. Sometimes a corbel or bolster is introduced, as shown in Figs. 8 and 9. That shown on Fig. 8 has the objection that it is apt to rock. Occasionally ample bearing surface can be obtained by allowing the rail-bearers to overlap on the points of support as shown on Pl. LXVIII., Fig. 1. Where two rail-bearers only overlap on the points of support, the position of the rail is vertically between them as shown in Pl. LXVII., Fig 1. The use of steel joists as rail-bearers is shown on Pl. LXXVII. with the roadway suitable for ordinary vehicles as well.

Trussed rail-bearers.

3. Where iron is obtainable it may be convenient to economize timber by trussing the rail-bearers and so lengthening the spans. One method of doing this is shown on Pl. LXVIII., Figs. 2 and 3. The correct dimensions for the tie rods should be obtained by the graphical method. In order to make up for settlement, camber should be given to the rail-bearers and allowed for in cutting the posts. For a 30-foot span about 1 inch is sufficient. Trussed rail-bearers.

The points of support.

4. For military railway bridges these will generally be crib-piers or trestles. In deep water piles will be necessary, unless the bed of the river is rock. They may also be used when the river bed is soft. These are dealt with in Sec. X, para. 8, *et seq.* The points of support.

The special advantage of crib-piers is that railway sleepers can be used for them, that they are quickly made and require little skilled labour. (Pl. LXIX.) Up to 18 feet height crib-piers are most satisfactory. Between 18 feet and 25 feet the speed of building these piers decreases rapidly, and they are not so efficient. This is not only on account of the height, but also because so much more material is used. Crib-piers.

For a single line :—

Up to 8 feet high, cribs should be of single sleeper width.
From 8 feet to 18 feet high, cribs should be of double sleeper width.
Above 18 feet high, cribs should be of treble sleeper width.

As a rule the maximum height of a sleeper crib-pier should not exceed 25 feet. They should be filled with stones or earth to render them less liable to destruction by fire, and should always be filled with stones if placed in water courses or water.

Where the piers have to be placed in water the layers under water should be fastened together, a floor being given to the lowest layer. This section can then be floated out and sunk where required by loading with stones, &c.

Where cribs of double and treble sleeper widths are used, layers of two or three rails should be used about every sixth or seventh layer, in order to bind the piers together.

Trestles.

5. Trestles may be used in the construction of low-level bridges on deviations, and will generally be employed in the second stage of reconstruction, the semi-permanent bridge at original level. They can be constructed up to practically any height. Pl. LXX., Figs. 1 and 2, show the standard type with alternative fastenings.

These may be used for trestles up to 25 feet high. For trestles under 15 feet high the cross-bracing may be omitted. Pl. LXXI. shows a trestle made of round spars.

For heights of more than 25 feet trestles should be built in two or more tiers, and it will be found convenient and is stronger construction to make the capsills of each tier of trestles all on the same level. The gradient, if any, is taken by the top tier. No tier above the lowest one should be more than about 15 feet in height. Pls. LXXII. and LXXIII. show a trestle of this type for a height of about 50 feet, which was erected over the Vaal River at Standerton during the South African War. The extreme width of the topsill was designed to facilitate th subsequent erection of permanent girders without cessation of traffic. Pl. LXXIV. shows another type of two-tiered trestle, in which the groundsill of the top tier and the topsill of the bottom tier are formed of 12-inch by 3-inch planks. This arrangement will sometimes be found to facilitate construction.

With all trestles of more than one tier it is essential to tie the junctions of the tiers longitudinally by stringers, as shown on Pls. LXXIII. and LXXIV.

In all trestle bridges, except very low ones, longitudinal diagonal bracing should be used to stiffen the structure in each tier of trestles.

When the approximate section of the gap to be bridged is known beforehand and that section is comparatively uniform, a considerable amount of time and transport may be saved by making all the trestles of the same size in a base or advanced workshop. The proper level of the bridge would then be obtained by erecting the trestles on crib-piers of the height necessary to suit the section. Time is also saved by this method when the piers are made *in situ.*

Foundations.

6. Where trestles or crib piers have to be placed in water it is necessary to prepare a level bed on which they will rest. When the river bed is rock or very firm ground, the points of support may be placed directly on it; but if not, foundations will have to be laid. These may consist of filled sandbags, but only as a temporary expedient, since they will not last. A better material is stone, or better still concrete in sandbags. Except on very hard ground the weight of a trestle and its load should always be spread from the groundsill on to cross timbers, which may be made of sleepers. **Foundation.**

With piers exposed to a current a most important point to attend to is the prevention of scour. This may be done by making an apron of stones or concrete bags beyond the part of the foundations actually required for carrying the load. The most dangerous place by far is the downstream end of the pier. These aprons should be carefully watched.

In rivers exposed to sudden floods it may be necessary to weight the cribs or trestles and to anchor them by chains or wire ropes to holdfasts on the banks. When floating débris is likely to be brought down, guard posts or piers should be placed on the upstream side of the bridge, just above each trestle.

Erection of trestles.

7. Trestles may be erected in the following ways:— **Erection of trestles.**

i. The trestles are put together on the ground, with the bottom sill so placed that it will be in its proper position when the trestle is raised. If the ground is uneven a staging should be made on which to assemble the trestle. When ready it is raised by means of tackle reaching from near the head of the trestle to rail level. As a rule, derricks will not be necessary. It will generally be best to hook the tackle to a sling fastened near the top of the uprights and not round the capsill. Care must be taken not to rack the trestle during the operation of raising. This is more likely to occur with trestles put together with dogs than these with drift-bolts, because dogs can only be driven on one side of the trestle before it is raised. Preventer ropes must not be omitted. As soon as the trestle is upright and in its correct position it should be braced to the last one already in bridge. The rail-bearers are then got out and fixed.

Where trestles cannot be put together at the exact spot for their erection, the assembling can be done at some convenient place close at hand, where they can be carried into position. Only trestles below 16 feet in height can be handled in this way.

ii. The trestles are put together on the bank and then picked up and placed in position by means of an improvised crane running on the rails, which are laid on the bridge as it progresses. This crane may be formed of a couple of trussed 12-inch by 12-inch timbers 5 to 6 feet longer than twice the interval between the trestles. It should be mounted on a truck axle by means of a pair of axle plummer blocks, or better still on the floor of a truck. The tail of the crane should be secured to a loaded truck behind it.

iii. Derricks are erected on either side at bank level and the trestles placed by means of the two derricks working together. This may be feasible in the case of narrow gaps where method (i) is not applicable.

iv. The trestles are built up in their positions. In an awkward site and with heavy timbers this will probably be the quickest method. The trestles should have been fitted together previously and the pieces numbered. An overhead cableway will assist materially in the erection of a long bridge.

Where there is more than one tier of trestles to be placed any of the above methods may be employed. In the case of method (i), after the bottom tier is placed a temporary platform must be laid on the longitudinal stringers joining the capsills of the trestles. The next tier may then be assembled on this platform and raised as before.

Time of construction.

Time of construction.

8. Circumstances vary so much that it is practically impossible to give any accurate rules for the time required to construct a railway bridge. The following table, however, of details of some of the bridges constructed during the South African War, may be of some assistance in arriving at an estimate :—

Work done.	Labour.	Time.
3,300 yards of deviation. 100 yards of bridge carried on 6 trestles, 4 to 5 feet high, and 12 on rebuilt stone piers	2 coys., R.E., 1,200 infantry, 300 natives	11 days.
2,156 yards of deviation, 64 yards of bridge carried on cribs, 6 to 15 feet high	2 coys., R.E., 400 infantry, 33 civilians, 450 natives	6 days 1½ hours.
1,254 yards of deviation, 50 yards of bridge carried on 5 cribs, 19 to 34 feet high	150 R.E., 55 infantry, 600 natives	5 days 12½ hours.
528 yards of deviation, 64 yards of bridge carried on 7 cribs, 7½ to 33 feet high	150 R.E., 55 infantry, 600 natives	3 days 1 hour.
140 yards of bridge, including raising of one 105 feet girder and seven 30 feet trussed spans carried on 12 trestles, 38 to 62 feet high	4 coys., Railway Pioneer Regiment	31 days.
59 yards of bridge carried on 6 cribs, 10 to 31 feet high	100 R.E., 17 civilians, 380 natives	3 days 2 hours
162 yards of bridge carried on 16 cribs, 7 to 13 feet high, and 18 trestles, 13 feet high	1 coy., R.E., 100 natives	12½ days.
48 yards of bridge carried on 2 cribs, 5½ feet high, and 8 trestles, 6½ to 13 feet high	140 R.E., 20 infantry, 500 natives	3 days 18 hours.
37 yards of bridge carried on 3 cribs, 14 to 23 feet high (very difficult foundations)	90 R.E., 30 infantry, 300 natives	2 days 12½ hours.
110 yards of bridge carried on 11 cribs, 7 to 18 feet high, and 5 trestles, 17½ feet high	90 R.E., 30 infantry, 300 natives	4 days 7 hours.

In railway bridge work a large amount of unskilled labour can be employed. In temporary repairs it has been found that the proportion of unskilled to skilled labour may be roughly as 7 to 1, while in semi-permanent or permanent work it may be taken as 3 to 1.

If proper lighting arrangements are provided, work may be carried on at night almost as well as by day. The best form of light is probably the acetylene flare. Next come the oil flare, and lastly electric light. Although this last is the most powerful it requires most plant, takes most time to prepare for action and throws deep shadows.

Strutted railway bridge.

Strutted bridge.

9. When the total span is small (30 to 40 feet) and the bottom unsuitable for trestles, a bridge of the kind shown on Pl. LXXV., may be used instead of trussing the rail-bearers. (The employment of this type of bridge will probably be rare.) Very careful work is required in fitting the inclined frames to the distance pieces. To enable this to be done an exact section must be marked out on the ground, so that the mitred ends may be cut accurately.

If possible the rail-bearers should be continuous over the whole span. If their length is not sufficient for this they should butt over the tops of the frames, and, if long enough, break joint. Where they are not continuous over the whole span it will be well to add additional bracing, as shown by the dotted lines.

In erecting this bridge the inclined frames should be made on their respective banks and then lowered until the feet are in position, when they should be inclined forwards. The distance pieces must then be got out and the frames lowered until they engage with them. The junctions must then be dogged on both sides or fastened with cover-plates. If dogs are used the corresponding pairs, on opposite sides of the timber, should be driven at the same time.

A pair of small derricks will be found useful in erecting this bridge.

This form of bridge becomes more simple when the inclined members rest against the bottom sills of the trestles or the feet of the abutments. In such cases these members can be single baulks and not frames.

Repair of bridges.

Repair of bridges.

10. The bridges already described may be used to replace those broken by the enemy, but in certain circumstances other methods may be adopted.

Small culverts may be filled in with earth or stones if no stream is running. These embankments are liable to be washed out should floods arise, but they may be the quickest means of restoring communication when other material is not at hand, and, in any case, they can be easily replaced by bridges when more time and material are available.

In cases where the girders of a bridge have been cut through near one end it may be feasible and economical to raise the girders to their original position, supporting the broken end on a crib-pier or a trestle.

Pl. LXXVI., Figs. 1, 2 and 3, show examples of bridges repaired in this manner during the South African War.

In the case of bridges shown on Pl. LXXVI., Figs. 2 and 3, damaged members of the girders were replaced by wooden beams.

It may be practicable to make up the parts of a damaged girder in existing railway workshops. They can then be sent out to the site of the bridge, and riveted on the girder in replacement of the damaged parts.

Girders can also be taken from positions where they are not immediately necessary, and erected where they are urgently required. For instance, shore spans can be hauled over to close destroyed centre spans. The shore spans, which are usually low, and possibly over a dry bed, can be filled up with temporary bridgework. Girders are either built up on temporary staging in the river, or river bed, and then raised into position, or they may be launched.

In launching one span, an intermediate trestle must be fixed. In launching two spans together no intermediate trestles are required, but the two spans must be bolted together, and possibly trussed above to prevent sagging.

If a temporary bridge has been built on the site of the permanent bridge with rails at the original level the girders can be carried out on railway trucks and dropped on to the piers.

Pl. LXXVI., Fig. 4, shows the case of a broken arch replaced by a trestle bridge.

When using square timbers for railway bridges the following rough rule holds good for loads to be carried on English railways. Two 12″ × 12″ baulks under each rail will cross a 12-foot gap, two 14″ × 14″ a 14-foot gap, &c.

Use of square timber and W.I. beams.

Such timbers may be used in groups (Pl. LXVII., Figs. 1 to 5) so that each carries its fair share of the road. Pl. LXXVII. shows the use of 12″ × 5″ W.I. beams, 42 lbs. per foot run, as road bearers for a metre gauge railway. For the ordinary loads of engines and trucks on this gauge four girders (Fig. 9) will form a roadway for a clear bearing of 26 feet; while for spans of 15 feet only two girders are required (Fig. 10). Both these roads are shown suitable for ordinary vehicles as well, which is often a matter of necessity in military railway bridges. Fig. 10 roadway dimensions are for the 4-foot $8\frac{1}{2}$-inch gauge.

Plates should be provided with these beams to act as fish-joints or cover-plates when beams are placed butt to butt, using $\frac{5}{8}$-inch bolts and nuts for fastenings, and they can also be used as sole plates under the ends where the flanges bear on abutments or supports.

The following stores are required for fastenings of these bridges:—

Stays, 2 feet long, of $\frac{3}{4}$-inch round iron Tie rods, 5 feet 3 inches long of $\frac{7}{8}$-inch round iron	} with nuts and washers.

Bolts for cover or sole plates, $\frac{7}{8}$-inch diameter.
Wood screws, 9 inches long.
Dogs, iron, 15 inches long of $\frac{5}{8}$-inch square iron.
McMahon spanners, 14 inches.
Augers, bull-nosed, $\frac{7}{16}$-inch, $\frac{1}{2}$-inch and 1-inch.
Spike nails, 8 inches and 6 inches.

Section XIV.—IMPROVISED BRIDGES AND THE PASSAGE OF RIVERS BY MEANS OF IMPROVISED MATERIAL.

1. Circumstances may often arise which render the passage of a river imperative when no service bridging material is available.

Ingenuity and an inventive turn of mind now has its chance of showing what can be done with materials at hand.

In this section some improvised methods are described which have been actually utilized, but the examples given are not in any way an exhaustive statement of what may be done. Everything depends upon the material available and the ingenuity of the individual who is in charge of the work.

Boat bridges.

Bridges made of boats.

2. The building of a bridge from boats found locally is the commonest method of improvising a crossing when service material is not available, provided that their removal or destruction has been omitted by the enemy, but skilled carpenters are required for the work which will take a considerable time.

Buoyancy of boats.

3. On rivers, &c., the boats or barges are sometimes of a nearly uniform section; this sectional area, multiplied by the length, will give the displacement. The displacement in feet multiplied by $62\frac{1}{2}$ lbs. (the weight of a cubic foot of fresh water), less the weight of the boat in lbs., gives the actual buoyancy of the boat in lbs. Of this not more than two-thirds should be taken as available with undecked boats.

With boats in the water and sufficient men, the easiest way to obtain the available buoyancy in lbs. is to multiply 160 by the number of unarmed men the boat will hold safely, *i.e.*, without being immersed deeper than within 1 foot of the gunnel. (The weight of an unarmed man is taken to be 160 lbs).

Rough rule for intervals between boat piers.

4. The weight of four unarmed men = 4 × 160 = 640 lbs. = 560 + 80 lbs.; the load per foot run on the bridge with infantry in fours crowded by a check (para. **6**, Part IIIA., Sec. III.) = 560 + 80 lbs. (taking the weight of the superstructure per foot run as 80 lbs.), therefore the following rule holds.

The number of unarmed men the boat will hold safely divided by 4 = central interval in feet between the boats carrying the above load.

In calculating the interval, however, the rule as to clear waterway (Sec. VII, para. **10**) must not be forgotten. Thus a

28 feet cutter holding 50 men, and floating with 1 foot of gunwale above water, would have an available buoyancy (para. **3**) of $160 \times 50 = 8{,}000$ lbs. And the central interval between the boats in bridge to carry infantry in fours would be—

$$\frac{50}{4} = 12 \text{ feet } 6 \text{ inches.}$$

This, with a boat 7 feet 6 inches wide, would allow a waterway of only 5 feet, which is insufficient; the boats would therefore have to be placed in pairs (para. **11**, and Pl. LXXVIII., Fig. 1) and further apart.

5. When the above method cannot be adopted the displacement may be accurately calculated by means of Stirling's Rules. **Stirling's rules.**

The boat to be measured is considered as being divided by equi-distant athwartship or transverse vertical planes, the boundaries of which planes give the external form of the vessel at the respective sections, and therefore, approximately, the forms of any intermediate portion of it.

If the boat be immersed to the line AB (Pl. I., Fig. 5) as the line of the proposed deepest immersion, the curves H O, K F, (Fig. 3) would give the external form of the boat at the positions G and I in that line, and the areas are G H O, I K F. If the areas thus obtained (the sections being taken at equal intervals) be represented by linear measurements, and are set off on lines drawn perpendicularly to AB at the respective distances apart of the sections, a curve bounding the representative areas would be formed, which is calculated by one of the following rules, and gives the solid content of the immersed portion of the half boat in cubic feet.

The usual practice is to consider only half tbe boat, and to divide it by equi-distant horizontal and vertical planes, the latter being perpendicular to the keel.

Rule I.—Divide the base of the curve to be calculated into an even number of equal parts.

$$\text{Then the area } = (A + 4\,E + 2\,R)\frac{r}{3}.$$

Where A = the sum of the first and last ordinates W_1 and W_{13}.

E = the sum of the even ordinates W_2 W_4 . . W_{12};

R = the sum of the remander, W_3 W_5 . . W_{11};

And r = the common interval of the ordinates.

Rule II.—Divide the base of the curve into such a number of equal intervals as will be a multiple of 3, then the ordinates will be a multiple of 3 with one added (Fig. 2).

$$\text{Then the area } = A + 2\,F + 3\,R)\,\frac{3r}{8}.$$

Where A = the sum of the first and last ordinates, W_1 and W_{16}.

F = the sum of the fourth, seventh, tenth, and thirteenth;

R = the sum of the remaining ordinates,

and r = the common interval of the ordinates.

Example of the application of Stirling's rules.

6. The drawings of a 28-feet cutter are given in Pl. I., where Figs. 4, 5 and 6 are respectively an end elevation, a side elevation, and a half plan. The dotted line represents the safe load water line of the boat; the chain dotted line represents the contour of a horizontal plane midway between the safe load water line and the keel, and at a distance of 0·7 foot from each. The boat is divided into two at its greatest breadth, x, by a vertical plane, and the distance from x to the bow is cut by two vertical planes A, B, dividing it into three equal lengths of 4·12 feet. Similarly, the distance from x to the stern is divided into three equal lengths of 4·9 feet by the vertical planes, 1, 2. These half-sections are shown in Fig. 4.

The following table gives the lengths of the intersections of the several planes, as taken from the left half of Fig. 4 for the after-part of the boat, and from the right half for the fore-part:—

Horizontal Plane.	With Vertical athwartship Planes.							
	Stern.	2.	1.	x.	x.	A.	B.	Bow.
	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	Feet.	
Safe load water line	0	2·2	3·24	3.52	3·52	2·98	1·68	0
Middle	0	1·0	2·52	3.0	3·0	2·24	1·0	0
Keel	0	·14	·14	·14	·14	·14	·14	0

The area in square feet of each vertical half-section is found by Rule I. as they are divided into an even number of equal parts:—

——	For Stern.	For Bow.
½ area at stern = ...	= ·0	...
„ 2 = (2·34 + 4 × 1 + 0) ⅓ × ·7...	= 1·48	...
„ 1 = (3·38 + 4 × 2·52 + 0) ⅓ × ·7...	= 3·14	...
„ x = (3·66 + 4 × 3 + 0) ⅓ × ·7...	= 3·65	= 3·65
„ A = (3·12 + 4 × 2·24 + 0) ⅓ × ·7...	...	= 2·82
„ B = (1·82 + 4 × 1 + 0) ⅓ × ·7...	...	= 1·35
„ bow = ...	...	= 0

Two new curves UVW and WXY (Fig. 7) are constructed each with ordinates dividing its base into three equal portions of 4·9 feet and 4·12 feet respectively, the ordinates being of lengths corresponding with the areas of the vertical sections already found. Then by Rule II. the volume—

$$\text{From W to stern} = (3{\cdot}65 + 0 + 3 \times 4{\cdot}62)\tfrac{3}{8} \times 4{\cdot}9 = 32{\cdot}1734$$

$$\text{,, W to bow} = (3{\cdot}65 + 0 + 3 \times 4{\cdot}17)\tfrac{3}{8} \times 4{\cdot}12 = 24{\cdot}9672$$

and the total displacement is, therefore, 2(32·1734 + 24·9672) feet, which, multiplied by 62½ lbs., gives 7,142·5 lbs. total buoyancy. Deduct the weight of the boat, 1,834 lbs., and the available buoyancy is 5,308·5 lbs.*

7. With a boat afloat and empty, an easy application of Stirling's rule is to calculate the volume of that part between the water line and the safe load line; the available buoyancy in lbs. is $62\frac{1}{2}$ times the volume in cubic feet so found. Calculation of buoyancy of boats afloat.

8. The following table, giving the dimensions and weights of the various boats used in the Royal Navy, will be useful for roughly determining the weights of open boats of other classes† :— Table of dimensions of boats.

Description of Boat.	Dimensions over all.						Weight in lbs.	Available Buoyancy in lbs.
	Length.		Breadth.		Depth.			
	ft.	ins.	ft.	ins.	ft.	ins.		
Launch	42	0	11	0	4	3	8,400	20,100
"	40	0	10	6	3	9	7,336	15,250
"	36	0	9	6	3	4	6,132	11,400
Pinnace	32	0	9	0	3	3	4,088	10,100
"	30	0	8	7	3	1	3,688	10,400
"	28	0	8	4	2	10	3,508	9,300
"	26	0	8	4	2	10	2,926	7,950
Barge	34	0	8	2	2	9	2,520	10,000
"	32	0	8	2	2	9	2,296	9,500
Cutter	30	0	8	0	2	$8\frac{1}{2}$	2,016	9,150
"	28	0	7	6	2	$6\frac{1}{2}$	1,834	7,800
"	26	0	7	3	2	$6\frac{1}{2}$	1,138	7,250
"	25	0	7	3	2	$6\frac{1}{2}$	1,092	7,200
"	23	0	6	11	2	$6\frac{1}{2}$	952	6,600
Jolly boat	25	0	7	3	2	$6\frac{1}{2}$	1,092	7,200
"	23	0	6	11	2	6	952	6,600
"	18	0	6	0	2	2	734	3,600
"	16	0	5	7	2	1	602	2,800
Gig	30	0	5	6	2	2	896	6,700
"	28	0	5	6	2	2	840	5,500
"	26	0	5	6	2	2	756	4,550
"	24	0	5	6	2	2	578	4,300
"	22	0	5	6	2	2	518	4,000
Cutter gig	20	0	5	7	2	3	560	3,200
Galley	32	0	5	6	2	2	1,008	3,800
Whale boat	27	0	5	2	2	1	728	2,350
Dinghy	14	0	5	2	2	1	476	1,500
"	12	0	5	2	2	1	378	1,500

* In this case the safe load water line has been taken very low down; thus accounting for the smallness of the available buoyancy.

† The *Register* tonnage (R.T.) of ships is $\frac{1}{100}$ the cubic content in feet below the upper or tonnage deck, exclusive of engine rooms. The average *Dead-weight* cargo in tons = R.T. × $1\frac{1}{2}$. Thus a boat of 4 tons R.T. would carry in bridge, at least 6 tons load on a bay. The average *Measurement* cargo (at 40 cubic feet to the ton) = R.T. × $1\frac{7}{8}$. The actual weight in tons of small vessels is about $\frac{2}{3}$ that of their R.T.

Preparation of boats for bridging.

Preparation of boats for bridging.

9. Boats are used either singly or in pairs to form the piers of a floating bridge. The case of boats used singly will be considered first.

The baulks rest on a central *saddle beam*, A B (Pl. LXXIX., Fig. 1), which should be fixed longitudinally in the centre of each boat its upper surface being raised a little above the gunwales, and its length depending on the width of roadway required. In large boats with strong sides this saddle may be fastened on beams laid across the gunwales (Fig. 5), but in boats of slight build it should be supported on the kelson, as shown in section (Fig. 4). The baulks are laid from saddle to saddle, and secured by pins or lashings.

Another way to strengthen weak boats is to support the saddle on cross-pieces with cleats, which grip the gunwales, and prevent them from being thrust out by a load.

Baulks may also be laid on a sort of midship deck, their ends abutting against a middle piece of timber, thus preventing two boats from coming nearer to each other (Fig. 3).

When barges or large lighters of a capacity of 20 tons and upwards are available, and the timber for baulks is short, gunwale pieces of wood, with cleats to receive the baulks, may be laid on each gunnel, and the baulks laid across from the outside gunwale of one boat to the nearest gunwale of the next, other baulks being laid across from gunwale to gunwale of each boat.

Men and time for fitting a boat.

10. Two carpenters would fit up a boat, as in Fig. 4, complete in about four hours, supposing the timber to be ready to hand, of the necessary scantling, and requiring merely to be cut to the proper length, and fitted to the boat. They would want twenty 6-inch spikes and thirty-six 4-inch clasp nails, in addition to the ordinary carpenters' tools.

Double boat piers.

11. In making boat bridges, if the boats be not each buoyant enough to form a pier, they may be used in pairs (Pl. LXXVIII., Fig. 1). The sterns are lashed together, and the spars AA_1 and BB_1, are held over the side; four 2-inch ropes at CD, EF, C_1D_1, E_1F_1, are passed under the boats and secured to the poles, and four double ropes are passed round the latter at the same points and cross over the boats; these latter ropes are racked up tight. Cross-pieces MM are then lashed to the poles and thwarts, and blocks on the thwarts at KK support the saddle beam, which is lashed to the thwarts, and to the stern rings of the boats. The thwarts are also supported by struts on the kelson.

Half barge piers.

12. When only a few large boats, like barges, are to be got, they may be halved, by building amidships two well stiffened water-tight bulkheads, within 2 or 3 inches of each other, and then cutting the boat in two with saws. This has been done with boats afloat.

13. The getting into position of the boats, and laying the roadway, will much resemble the manner of forming a pontoon bridge from rafts. The boats in a tidal river should be moored alternately stem and stern up-stream. Forming bridge of boats.

Bridge may be swung and cuts formed, if required, as described in Sec. VII., paras. **92–98**.

Barrel bridges.

14. Barrels or other enclosed watertight vessels may be used by themselves to float guns or wagons across rivers by attaching them to the frames and wheels. Under ordinary circumstances, however, these articles are made into piers, and the piers formed into rafts or bridges. Barrel bridges.

15. If the barrels or other vessels available are not included in the table below it is necessary to calculate their buoyancy. Not more than nine-tenths of the *actual buoyancy* shall be considered as *safe*. Buoyancy of barrels. Safe buoyancy.

16. It has been found by actual experiment that the following rule is more accurate than any of those generally given for finding the buoyancy of a barrel, as well as being more simple for use. Collins' rule.

By this rule the *actual buoyancy* of a barrel in lbs. is given by the formula—

$$5\ C^2\ L - w,$$

where C is the circumference of the barrel in feet, half-way between the bung and the extreme end A B (Pl. LXXXI., Fig. 5); L is the length C D in feet, measured along a stave, exclusive of its projections, and w is the weight of the barrel in lbs.

17. As the buoyancy of the material of a barrel is very small, a simple practical rule for finding that due to its displacement, when the contents in gallons is known, is to multiply the number of gallons by 10, which gives a result in lbs., a little less than the actual buoyancy, or a little more than the safe buoyancy. Thus, to take the most unfavourable case in the table, a 72-gallon barrel by this rule should have a buoyancy of 720 lbs., which is only 57 lbs. short of the actual buoyancy (para. **16**). Rough rule.

Table of barrels.

18. The following are dimensions, weight, and buoyancy of a number of barrels :—

	Name of barrel.	Capacity in imperial gallons.	Dimensions. Extreme bung diameter.	Dimensions. Extreme length, exclusive of projections measured along the stave=L.	Dimensions. Circumference at ¼ length=C.	Weight when empty =w.	Actual buoyancy.
			ins.	feet.	feet.	lbs.	lbs.
Barrels used in the trade.	1. Ledger	170	38·5	4·52	9·33	252	1,736
	2. Butt	108	33·3	3·97	8·09	174	1,125
	3. Puncheon... ...	72	30·7	3·20	7·57	140	777
	4. Hogshead	54	28·6	2·76	7·05	119	567
	5. Barrel	36	25·3	2·42	6·23	88	382
	6. Half hogshead ...	26	22·7	2·12	5·61	65	269
	7. Kilderkin	18	20·3	1·81	5·02	49	185
	8. Small cask ...	14	18·3	1·76	4·49	32	146
	9. ,, ,, ...	6	13·8	1·37	3·40	20	60
Powder barrels.	10. Whole barrel ...	—	17·5	1·58	4·26	28·5	115
	11. Quarter barrel ...	—	14·0	1·07	2·99	8·5	39
Casks, vats.	12 Tun	—	40	3·2	9·96	95·0	1,477
	13. Three-quarter tun	—	32	3·2	8·69	74·0	1,134
	14. Half tun	—	31	3·3	7·75	67·0	903
	15. Quarter tun ...	—	27	2·5	6·61	51·0	499

Examples of calculations for barrel bridges.

19. The distance apart of and number of barrels in piers depend on their size, on the weights to be carried, and on the spars available.

Thus, suppose that spars, 21 feet long, and puncheons are to be had, and that infantry in file and 18-pr. Q.F. guns and limbers (unhorsed) have to cross the bridge.

The roadway need not be more than 6 feet wide; and in order that the piers may be twice as long as the width of the road (Sec. VII., para. 9) suppose the piers to be made of six casks each.

They will then be $6 \times 30{\cdot}7'' = 16{\cdot}3'$ long.

The actual buoyancy of each cask is

$$5 \times (7{\cdot}57)^2 \times 3{\cdot}2 - 140 = 777 \text{ lbs.},$$

and the safe buoyancy is

$$\frac{9}{10}\ 777 = 700 \text{ lbs.};$$

so that six of them will support 4,200 lbs. or 37·5 cwts.

Assuming the weight of the superstructure to be 70 lbs. per foot run, the load with infantry in file will be $280 + 70 = 350$ lbs. per foot run; and for them the piers might be at central intervals of $4{,}200 \div 350 = 12$ feet.

But piers at this interval will not support the gun, for when the gun wheels are over one pier, the limber wheels, 9 feet

11 inches distant, will be 2 feet 1 inch from the next pier, so that one pier may have to support

$$3{,}100 + \frac{2 \cdot 08}{12} \times 2{,}200 = 3{,}480 \text{ lbs.}$$

besides 840 lbs. of superstructure.

Thus, either the intervals must be reduced or the number of casks in each pier must be increased. The latter will be the better plan; and it will be found that with eight casks in each pier the central interval for either infantry or the gun may be 16 feet. The spars are just long enough for the gunnels of the piers, and as road-bearers they will rest well over both gunnels of both piers, and the waterway is ample.

Again, suppose that a bridge is required to carry the 60-pr. B.L., Mark I., and infantry in fours, and that butts are available, safe buoyancy 1,125 lbs. each.

The distance between the fore and hind wheels being 13 feet 11 inches, suppose the central intervals are made 12 feet each. Then the greatest load on any pier will be that on the gun wheels, viz., 7,460 lbs., together with the superstructure, say 120 lbs. per foot run = 1,440 lbs., total, 8,900 lbs. Now 8 butts have a safe buoyancy of 9,000 lbs. and the length of pier will be $8 \times 33 \cdot 3 = 22$ feet 3 inches. This will require long stiff timbers for gunnels, but if composite piers are made, though the length of pier will be just sufficient, the bays will have to be much increased to allow for waterway.

Composite piers.

20. Large piers of small casks may be formed by first making piers of two to four casks (Pl. LXXX., Fig. 4); these are placed touching each other, and two baulks, which carry the road bearers, are secured to their gunnels.

Piers of two rows.

21. A pier of two rows of casks may be made. Two braces for each cask are first fastened to a baulk, and stretched out perpendicularly to it; the casks are then placed end to end on each side of the baulk, and over their own braces. On the casks are laid two gunnels, previously lashed together at the ends, and at two intermediate points, by lashings which have afterwards to be racked up; the distance from out to out of the gunnels should be less than a bung diameter. The braces are then secured to the gunnels by two round turns and two half-hitches. The four lashings connecting the gunnels are then racked, the two at the ends are secured to the baulk by lashings, which are racked up, and, finally, the pair of braces on each cask are laced together as tightly as possible, so as to counteract the tendency of the braces to slip over the ends of the casks. This can readily be done by the spare end of one brace on each cask after it has been secured to the gunnel, figure-of-eight knots being previously made in each brace to prevent the lacing from slipping upwards (Sec. VII., para. **111**, *et seq.*).

Piers of head-less casks.

22. Provision casks, without heads, are often available; they may be formed into piers (Pl. LXXX., Figs. 5 and 5A) of a width greater than their height by pinning the four lower gunnels to the casks with trenails, and tying them together with battens between the casks in three or four places. The four top gunnels can be nailed to the casks from the insides, and these gunnels are connected by cross-pieces, which carry a saddle beam. These piers can be launched on three planks as ways. The end casks may be covered if the water is rough.

Framed piers. **23**. Pl. LXXX., Figs. 6 to 12, shows a part of a frame of timber for a pier of seven barrels, which might be used where rope is not to be got. The frame is connected by horizontal and vertical tie pieces, dovetailed and spiked, or trenailed to the longitudinal pieces, as shown in Fig. 9. With unskilled labour the pieces may be only halved with a saw and spiked, as shown in Figs. 10 to 12. All the pieces of the same length should be interchangeable. The longitudinal pieces are hollowed out a little where they are in contact with the barrels. The bottom pieces having been framed together, the barrels would be rolled upon them, the top frame laid on, and the whole connected with the vertical tie pieces; lastly the side and end planks would be spiked on. Round timber will answer, but it will take more time to fit together. The road bearers might each rest on both the top longitudinals, or a saddle might be added as shown. Frames of this sort might be made at a distance, carried up in pieces, and put together on the spot.

24. Barrels should not be kept dry for any length of time, and when they have been long empty, should be soaked in water before being used.

25. Whenever barrels are used for forming piers, they should always be placed with the bungs in an accessible position so that a pump may be used to remove any water that finds its way through the staves.

Barrel rafts.

Formation of barrel rafts. **26**. The general arrangement of a barrel raft is as follows (Pls. LXXX. and LXXXI.) :—Across the ends of the gunnels tie-baulks are lashed; these keep the piers in position, and when they are secured, the baulks can be laid; these do not need to be lashed, if square. The baulks (Pl. LXXXI., Fig. 1) are shown overlapping, and so the ribands (if they are of the same length as the baulks) have to overlap also, as in Pl. LXXXII. For troops this does not matter, and oars, &c., do for ribands, but for wheel traffic the ribands must be large, and it is better to have them butting over the centres of the piers; to do this, the outer baulks must either be spliced and lashed down (Pl. L., Fig. 2), or else be allowed to butt over the centre of the piers, being lashed to the gunnels they bear on. The chesses are then laid as in pontooning.

Rowing rafts. **27**. When rafts have to be rowed, outriggers may be made of short baulks (Pl. LXXXI., Fig. 4), with 1-inch hard wood trenails as thole pins. They can only be rowed in still water, and are unmanageable in a current.

Rafts made of barrel piers are very useful for conveying heavy stores which cannot be stowed in a boat, for bridge ends, for placing trestles and piles, and also for diving from, &c. When well made they will remain fit for use as long as the slings and braces are secure. If, however, a raft is kept too long in the water the ropes will rot, and the raft may break up at any time.

Forming bridge from rafts.

In forming bridge from rafts, the quickest way, when there are enough piers, is to allow the outer piers of each raft (which may consist of from two to six piers) to touch as at P in Pl. LXXXII., Fig. 2, but the waterway is much reduced thereby. Otherwise each raft carries out a bay with which to connect, as in pontooning.

Stores for one raft.

28. The stores for a raft of two piers at 10 feet central interval to carry infantry in fours crowded, or 18-pr. B.L. guns are :—

Stores.	No.	Dimensions.*		Weight. lbs.
		Length.	Size.	
Barrels	14	4′ 3″	2′ 9″ and 2′ 2″... ...	2,336
Gunnels	4	21′	5″ × 4″	458
Slings	4	6 fms.	$2\frac{1}{2}$″ tarred rope ...	36
Braces	24	3 ,,	$1\frac{1}{2}$″ ,, ,, ...	41
†Tie-baulks	2	15′	4″ round spars... ...	103
†Tie-baulk lashings ...	8	3 fms.	1″ rope	7
†Baulks	5	14′	5″ round or 4″ × 6″ ...	640
†Ribands	2			
†Chesses	10	10′	12″ × $1\frac{1}{2}$″	450
†Racklashings	6	1′	$1\frac{1}{2}$″ round wood	10
		1 fm.	$1\frac{1}{2}$″ rope ...	
Outriggers	2	...	... ...	say 50
Boathook	1	16′	... ...	10
Anchors	2	3′ 10″	2′	224
Cables	2	30 fms.	3″ rope	120
Buoys	2	2′	10″ diameter	10
Buoylines	2	10 fms.	1″ rope	24
Breastlines	2			
Pump	1	...	... ...	say 10
Total weight of single raft, anchors, &c.				4,529
† For the extra bay for forming into bridge the stores marked thus must be doubled in numbers. Their aggregate weight is				1,210
Total weight of raft and bay for forming into bridge				5,739

* These stores are those it is found convenient to use at Chatham; they are only types, and modifications would have to be made according to the materials available.

Cask foot-bridge.

29. Where casks are obtainable in small numbers only, light foot-bridges may be made in various ways.

A bridge of this description with a double footway suitable for infantry is shown on Pl. LXXXIII., Figs. 1 and 2. The stores required for each raft or 18 feet of bridge are:—

Casks, 54 gallons	4
Spars, 15′ × 3″ diameter	4
„ 15′ × 4″ diameter	4
Planks, 10 feet	8
Lashings, 2″, 9 fathoms	8
„ $1\frac{1}{2}$″, 6 fathoms	4

This bridge will bear infantry in single file at intervals of 4 feet on both footways at one time. As the footways are at the ends of the piers the bridge is suitable for swimming animals alongside.

Catamaran bridge construction.

30. Pl. LXXXIV., Fig. 1, shows a light foot-bridge, the piers of which are formed of single barrels and light poles lashed on the catamaran boat principle.

The piers are made as follows:—

Two poles (A—A) 12 feet long and 3 inches butt diameter are laid on the top of each barrel. Two short poles are then lashed to the poles (A—A), so as to form a frame through which the upward pressure of the water will not force the barrel. The barrel is also lashed to the poles (A—A) at the quarters.

The poles (A—A) should project beyond the barrel about 18 inches at one end.

The piers thus formed are connected at each end by pieces (B—B), which should overlap for the width of each pier.

The footway is formed with chesses or planks laced to the upper ends of the poles (A—A).

Stores required.

For each 9-foot bay of bridge—

1 54-gallon cask.
10 poles 12 feet to 16 feet long, 3 inches to 4 inches butt diameter.
6 lashings.

Bridges, rafts, etc., from improvised material.

Bridges, rafts, etc., from improvised material.

31. If boats and casks are not available, it is then necessary to improvise means of effecting the crossing from:—

(1) Materials included in the equipment of an army.
(2) Materials in the neighbourhood of the site of the crossing.

Under (1) may be included wagons, wagon or cart covers, tents and tent bags, waterproof troughs, tanks and sheets, biscuit boxes and tins.

Under (2), oil and beer barrels, growing timber and brushwood, timber from roof trusses and floors of adjacent buildings, reeds, rushes, hay, straw, and wire.

If the above materials are found in sufficient quantities to form the requisite number of floating piers and superstructure, bridges may be built of approximately the same form as described in Sec. VII; but improvised materials are generally more readily adapted to the construction of boats, rafts, and floats, and the following examples are given as a guide as to what may be done in this respect:—

32. Pl. LXXXIV., Figs. 3 and 4, shows how a light foot-bridge can be made with reeds, wire, and some planking. Reed fascine foot-bridge.

The reeds are cut in lengths of about 5 feet and bound into fascines about 12 inches in diameter.

These fascines are made into a continuous mat with rope or wire used as a Malay hitch.

The bridge is completed with a single-plank footway in the centre.

A somewhat more efficient bridge of the same nature was made in India. The fascines were 10 feet by 1 foot 6 inches; each fascine was tied to the next one with a grass rope, each fascine being again fastened to 3-inch hempen cables, which were stretched across the river, 8 feet apart, and lay on the top of the fascines near their ends. These cables were anchored to the banks.

The bridge was made in a series of rafts, which were constructed above the bridge and floated down to their position under the cables.

The bridge was finally stiffened by longitudinal poles lashed to the top of the fascines.

The length of this bridge was 20 feet. The current of the stream was $1\frac{1}{4}$ miles per hour.

The load carried was infantry in fours, and ponies, unloaded, could cross with ease.

33. Pl. LXXXV., Fig. 1, shows how a light bridge can be made of bamboos or light brushwood, no sticks more than 2 inches in diameter. Light brushwood bridge.

The bridge is constructed as follows:—

Two stout poles of about 3 inches diameter are obtained. Two uprights are then driven into the river bottom about 4 feet from the bank, two men sitting on the end of the poles, while other men sit on the in-shore ends, converting them into cantilevers. The men in front then lash on a transom, and then drive in stays front, back, and side, to the upright. The cantilever is then pushed forward until the end projects beyond the first transom about 4 feet.

The operation is then repeated.

The flooring is made of a brushwood mat, referred to in Military Engineering Part V, para. 10.

This bridge can be made in water 5 feet deep, with good holding bottom, at the rate of 18 feet per hour.

34. Pl. LXXXV., Fig. 2, shows a light trestle bridge made of hop poles. Each trestle consists of two legs and a ledger. The Hop pole bridge.

legs are lashed with sheers lashing (Part IIIA., Sec. V., para. **20**), at the required height, and opened out to one-third of the height of the lashing from the butts; the ledger is lashed close to the butts.

As each trestle is made it is carried to the head of the bridge and launched. The roadbearer and handrail are then lashed, leaving spare ends of sufficient length to be used to secure the roadbearer and handrail of the next trestle. The feet are then pushed out as far as possible (about 6 feet). The trestle is then raised to the vertical position and the inshore ends of the road-bearer and handrail lashed, by means of the spare ends of the lashing, to the in-shore trestle; or, in the case of the first trestle, to pickets driven into the bank.

Per 6-foot length of bridge:—

Stores required.

Spunyarn, ...	lbs.	$1\frac{1}{2}$
Hop poles		5

This bridge will carry a load of one man per bay.

Improvised drawbridge.

35. A drawbridge may sometimes prove useful in places where allowance has to be made for traffic on a river or canal and sufficient head room cannot be given.

The following is a description of a drawbridge made in Egypt. (Pl. LXXXVI., Fig. 1.)

The opening required was 30 feet.

The piers carrying the swing bays were made with 30-foot trestles strutted and tied back to the bank, and also side-strutted. The next trestles were 7 feet inshore of these, and the remainder at the usual 15-foot interval. Each half of the opening consisted of a 19-foot bay, bolted and nailed, so that the superstructure would not slip off when the bay was raised. A transom A was fixed just inshore of the centre of gravity of the bay, a sling from this to the top of the trestle carrying the weight of the bay when in motion, and also part of the load when the bridge was closed. The front transom B had also a sling to the top of the trestle which only took the weight when the bridge was closed. The pivot was formed by a sling passing round the rear transom C, and a transom fixed outside the trestle legs, this sling is always taut and governs the path of the bay in opening and closing the bridge.

Lifting ropes were fixed to the front transom, and were led through a snatch block on the end trestle of the standing portion. The best lead was found to be just above the top of the swing bay when the bridge was open, as the pull got heavier as the bay was raised.

Lifting tackles were fixed to the rear transom for closing the bridge; these tackles also partook of the weight when the bridge was closed. Short cut-baulks were provided in the centre, and the two swing bays finally pulled together by tackles which hooked on to pins in the ends of the front transoms, and took off some of the strain from the pivot sling when the bridge was fully loaded.

36. Pl. LXXXVI., Fig. 2, shows a simple method of making a secure footway over a marsh, provided canvas or similar material is available. Canvas track over marshy land.

37. When brushwood and some light waterproof material, such as canvas or calico, covered with india-rubber solution or prepared as described in para. **39**, are available, small boats may be made which may either be connected so as to form a light infantry bridge, or may be used for ferrying purposes on a small scale. Sheet boats.

The only tools required are a billhook or pocket-knife and a ½-inch auger.

The size of the boats chiefly depends on the materials available. The canvas carried by a pontoon troop is 2 feet 6 inches wide, so that three widths, joined together by a waterproof joint, formed by india-rubber solution, would admit of a boat 4 feet wide and 18 inches deep being constructed. In Pl. LXXXVII., Fig. 1, a length of 8 feet has been given to the boat, which is constructed as follows :—

The four pieces *a a*, *b b*, for the sides are cut 8 feet long, and should be about 2 inches diameter. The two marked *b b* are placed close together, and have holes bored through them at intervals of about 5 inches with the ½-inch auger. Into these holes are fitted the bars *c c*, 4 feet long and about an inch in diameter, having their ends pointed so as to fit the holes in *b b*. The frame so made forms the bottom of the boat.

The pieces *a a* are now placed one over each of the pieces *b b*, and ½-inch auger holes are bored downwards through them in the spaces between the bars, *c c*. Into these holes short bars, about 18 inches long and 1 inch in diameter, with ends reduced to ½-inch, are fitted, thus forming the sides of the boat.

The ends are made separately in a similar manner, and are inserted between the sides *a a* and *b b*, ½-inch pins being driven through holes bored as in Fig. 2, to keep the whole together. This completes the framework of the boat.

The waterproof covering is then put on and should be of such a size as to envelop the whole boat. It may be secured by eyelet holes, through which a cord is rove, as in Fig. 3, or by being tacked down to the top rails with a hammer and a few tacks.

Such a boat might be covered with a tarpaulin.

When connected up in bridge, the roadway, which may be a light plank, should rest on both gunwales, *a a*, of the boat, or a saddle beam should be introduced, as in Fig. 4.

38. The canvas skins of the boats can be waterproofed in the following manner :— Mode of waterproofing canvas.

(1) 1½ lbs. hard yellow soap, cut into thin shreds and boiled in 6 pints of water till well dissolved.

(2) Mix in by degrees while the solution of soap is hot, 20 lbs. of English spruce ground yellow ochre, and 2 lbs. of patent driers, and 2½ gallons of *best* boiled linseed oil.

Boat of G.S. wagon, Mark IX.

39. Pl. LXXXVIII, Fig. 1, shows how a serviceable boat may be made from a G.S. Wagon and its cover.

All the fittings must first be removed—*i.e.*, wheels, brake, pole, seat, and side raves, and drag-shoe, and, with their nuts, bolts, and pins carefully put aside so that they may be readily available when the boat has to be reconverted into a wagon.

The cover is spread out and the wagon-body placed in the centre.

All projections must be wrapped with grass, hay, straw, &c., to obviate injury to the cover.

The sides and ends of the cover are then folded into the wagon and lashed at each end with the cover rope.

Care must be taken to stretch the cover taut against the sides and ends of the wagon.

This boat will hold from four to six men. It may be punted with a light pole or paddled with shovels.

Boats of this description were used for ferrying troops across the Vaal River during the South African War, 1901.

Brushwood and tarpaulin boat.

40. Method of constructing the brushwood frame for a tarpaulin boat to carry 12 armed men. Tarpaulin 18 feet by 15 feet. (Pl. LXXXVIII., Figs. 2 and 3.)

The boat is built keel upwards.

Three parallel lines are marked out on the ground 3 feet 6 inches apart.

Along the centre line three uprights are driven into the ground 5 feet apart and standing 3 feet 6 inches at least above the ground. The keel is 15 feet long and is formed by lashing several stout rods together. It is tied horizontally to the uprights 3 feet above the ground, with one end projecting 4 feet 6 inches beyond the uprights. This end is bent down and inserted in the ground so as to form the bow. The ribs are formed as follows :—Long stout rods are pushed into the ground at about 1 foot 6 inches intervals along the outer lines, which should curve inwards so as to form the bow. The rods are then bent over the keel and opposite ones lashed together and also square lashed to the keel. To strengthen the frame pairing rods are worked in over the ribs and keel.

The gunwale is formed by pairing rods lashed to the ribs where they enter the ground, and two similar parallel rows of wicker are formed between the gunwale and the keel.

To give rigidity to the ribs and frame the boat is divided into four compartments by lashing three horizontal rods across alternate hoops formed by the ribs, commencing with the stern. The latter is further strengthened by a stern post square lashed to these rods.

To maintain the curve of the bow when the boat is removed from the ground a stay is carried from the top of the bow to the place where the second rib from the bow crosses the keel.

The uprights are then removed and the frame trimmed up, all projections being bound with straw or hay to prevent injury to the tarpaulin.

Before fixing on the tarpaulin it should be soaked to make it watertight.

It is spread on the ground and the frame placed diagonally on it in such a manner that the corner by the bow overlaps it by about a foot when raised. The corners opposite the sides of the boat are folded in so that the tarpaulin will just overlap the gunwale.

Wherever it is necessary to tie the tarpaulin to the frame a stone is put inside the tarpaulin and a noose passed round it from the outside, the free end of the rope can then be used for the lashing to the frame.

It is best to fasten the sides of the tarpaulin to the gunwale first and then form the bow and stern by *twisting* the end corners and lashing them inside the boat. (Fig. 3.)

Brushwood or light planks should be placed in the bottom of the boat to prevent the passengers injuring the tarpaulin with their boots.

Men must embark one at a time under the orders of an officer, who must see that the load is kept distributed.

All must sit down and strict boat discipline kept.

41. An improvised boat can be made by using a 600-gallon trough in the following manner (Pl. LXXXIX., Fig. 1) :— Water trough boat.

Lay out the waterproof trough on the ground and place upon it a plank 20 feet long, 1 foot wide and 1 inch thick, along its length. On this plank place 8 standards at an angle to one another of about 45 degrees and 2 feet 6 inches apart.

Along the tops of the standards lash boathooks on each side to act as gunwales. The canvas is then drawn taut up each side and secured to the boathooks by threading a tracing-line through the eyelet holes of the trough and around the gunwales, the ends of the trough being folded in "dogs-ear" fashion, as when fixing it up as a water trough.

At each end a small piece of timber or brushwood is placed across the boathooks to keep them in their correct position.

Straw or other soft material must be placed round the sharp points of the plank, boat-hooks, and standards, so as to prevent any damage to the trough.

When finished the boat is 20 feet long, 2 feet 3 inches wide, and 1 foot 3 inches deep. It will carry 8 men, and may be moved by paddling.

Time : six man-hours.

42. A raft consisting of four 18 foot by 15 foot tarpaulins stuffed with straw will carry a G.S. wagon. (Pl. LXXXIX., Fig. 2.) Raft made with tarpaulins and straw.

The best method of filling tarpaulins is to build up a frame of planks about 6 feet square and 2 feet 6 inches high. Then place two lashings, about 24 feet long, across the frame each way, and, over these, the tarpaulins, well soaked. Next fill the tarpaulins with straw, trampling it well down. The ends and sides of the tarpaulins are then folded over the straw, and the whole made into a compact bundle by securing the lashings across the top.

Two of these floats are then lashed together by means of spars, thus forming one pier, or half the raft. The other half is made in a similar manner. The two halves are then lashed to one another, about 3 feet apart, by means of four 16-foot roadbearers, and the planks forming the roadway laid across them.

With good tarpaulins the buoyancy will remain good for at least 8 hours.

Stores required.

Tarpaulins	4
Straw, trusses...	44
Planks...	16
Roadbearers, 4 inches diameter	4
Gunnels, 4 inches diameter ...	4—14 feet long.
Tie baulks, 4 inches diameter	2—12 feet long.
Lashings, 1 inch	40—to lash roadway.
Lashings, 1½ inches	16—to lash floats.
Towing lines, 2 inches ...	2
Punting poles	2

Single cask raft.

43. A single-cask raft to carry two men can be made from one 54-gallon cask, with the addition of two poles 3 inches to 4 inches diameter and 15 feet long, four smaller ones 4 feet to 6 feet long, and two pieces of planking, and necessary lashings (Pl. LXXXIV., Fig. 2).

Two long poles are lashed on each side of the cask, splayed out at an angle of about 20 degrees, and kept in position by two shorter poles at each end of the cask. Slings, which can be windlassed up, should be added underneath and at the sides of the cask to stiffen this framework. The outer ends of the two long poles should be secured by a piece of planking about 9 feet long, to keep them at the proper angle and act as a balance when the raft is afloat. Two vertical stays are added at the inside end of the cask, secured by lashings underneath and at each side, to which are lashed the oars. These are used by one man sitting on the cask, a piece of planking being added across the poles as a foot-board. The second man stands on the framework behind him, holding the stays or the shoulders of the man seated.

Time: 2 men, 2½ hours.

Raft made of ground sheets.

44. Each sheet must be well stuffed with straw and laced with tracing line, the ends drawn in and turned over the top. Dimensions, when finished, 4 feet 3 inches long, 1 foot 9 inches wide (Pl. LXXXIX., Figs. 3 and 4).

To form a pier, place 12 sheets stuffed with straw in a row, eyelet holes uppermost. Then place two light spars, 14 feet long, on top, 1 foot 3 inches on each side of the central line. At one foot from the end make fast a tracing line with a clove-hitch and two half-hitches. Pass the line under the end of the first ground sheet and up over the spar, taking round a turn. Each ground sheet will be lashed at each end in a similar manner. Finish off with two half-hitches round the spar.

To form a raft place two piers parallel 2 feet 6 inches apart. Lash to the spars on the piers two distance pieces, one at each end, with a diagonal lashing. Six chesses are placed centrally over the two piers and laced to the two outer spars, making a deck space of 10 feet by 6 feet.

This raft will support a load of 1,800 lbs.

Stores required.

Ground sheets	24
Straw, lbs.	240
Spars, light	4
Boathooks	2
Chesses	6
Tracing lines	2

Time.

Sixteen man-hours.

"Bird's-nest" raft.

45. A raft consisting of a circular fascine and a tarpaulin or wagon-cover 12 feet by 12 feet will carry from six to eight men (Pl. XC., Figs. 1 and 2).

Two circles are struck on the ground 6 feet and 8 feet radius respectively. Stout pickets, about 2 feet 6 inches long, are driven at intervals on these circles forming the cradles in which the fascine is made. In making the fascine, care must be taken that the brushwood is placed evenly round the circle and well pressed down. Bindings are put on at intervals of about 15 inches to 18 inches. The tarpaulin or wagon cover is laid on the ground and the fascine placed in the centre. Lengths of brushwood are now put in the fascine to form a floor. The ends and sides of the tarpaulin or wagon cover are now folded over the fascine and lashed securely across the top, great care being taken to ensure that the tarpaulin is so folded as to prevent water entering between the folds.

Stores required.

Brushwood, bundles		3
Wire or spunyarn	feet	60
Tarpaulin or wagon cover, 12′ 0″ × 12′ 0″		1

Time: sixteen man-hours.

Brushwood and tarpaulin raft.

46. Pl. XC., Figs. 3 and 4, shows a raft made of brushwood and tarpaulin in the following way.

Excavate a rectangular pit 7 feet long, 6 feet wide, and 1 foot deep. Place the tarpaulin centrally over the pit, forcing it well to the bottom. Then place the brushwood, from alternate sides and ends, all round the figure, butts down, and hard up against the walls of the pit, forcing it in diagonally at the corners. Fix a one-inch lashing to the two corner handles of the width of the tarpaulin. Two men stand on the brushwood in the centre, and three men at each of the two diagonal corners lift the tarpaulin and brushwood at their corners and force it towards the centre. The centre men pass the lashing already fixed through the opposite handle, haul taut, and make fast. The other two opposite corner handles, and the centre handles of the sides and ends are similiarly lashed, and, finally, all the other handles on the tarpaulin. The sides should be as high, and the centre as low, as possible.

This raft will carry sixteen unarmed men.

Stores required.

Tarpaulin, 21′ 0″ by 18′ 0″	1
Lashings, 1″	6
Brushwood, 8′ 0″ to 12′ 0″ long, 1″ to $1\frac{1}{2}$″ butt diameter, all twigs left on lbs.	330

Time: eight man-hours.

Section XV.—THE CONTROL OF TRAFFIC AT MILITARY CROSSINGS, BRIDGES, FORDS, &c.*

References.

1. The general principles affecting the control of traffic during the passage of rivers, are laid laid in F.S. Regulations, 1912, Pt. I., Chapter III., Sec. 32, and Engineer Training, 1912, Chap. VIII., Secs. 98–101.

Responsibilities.

2. At each point of crossing, whether it be a bridge, ferry, or ford, an officer of the General Staff will, as a rule, be given the control of the traffic.

To this officer the engineers will furnish all information of the crossing which will affect control. In the case of bridges, the maximum safe load; in the case of fords, depth, nature of bottom, direction and nature of approaches; in the case of ferries, the nature of the landings, and the safe capacity of the boats, rafts, &c.

The Engineers are usually responsible for the maintenance of the crossing.

Maintenance of crossings.

3. When an army crosses a natural obstacle, such as a river or ravine, a party of R.E. will, as a rule, be left behind at the crossing to maintain its efficiency so long as it may be required.

The maintenance of a crossing is directly affected by the observance or non-observance of the following rules:—

(*a*) Troops should adopt the march formation necessary for the crossing 100 paces before reaching the approach, and should not change it until the tail of the column is at least 100 paces from the head of the bridge or ford.

(*b*) Distances must not be opened out in the march unduly. Infantry must break step, files or sections must not be "closed up," and bands should cease playing, and any tendency to quicken the pace on a bridge must be checked.

(*c*) If a bridge sways the column must be halted till the swaying ceases.

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* *See* also Sec. VII., paras. 17 and 70.

(*d*) If a column is halted on a floating bridge, the wheels of guns and vehicles should be placed if possible midway between two boats.
(*e*) When crossing a floating bridge all mounted officers and men should dismount, except the drivers of draught animals.
(*f*) Draught and pack animals are to cross invariably at a walk.
(*g*) Cattle being liable to take fright should be driven over only in small numbers at a time, the bridge being given up to them entirely for the time of their passage. Their dung must be carefully cleaned off the bridge.
(*h*) Men crossing in ferries are not to change their position in a boat or on a raft without permission of an officer. Horses should be placed on a raft with their heads up stream. As a rule one man should be told off to each draught and pack animal on a raft.
(*i*) Wherever possible handrails should be provided to all bridges, and screens should be improvised to prevent the animals being frightened by the water or depth of the gap over which they are crossing.
(*j*) Mechanical Transport using a heavy pontoon bridge should move at not less than 20 yards distance and the speed must not exceed 3 miles an hour.
(*k*) The bridge must be carefully watched the whole time during which the troops and transport are using it, and any re-adjustments or repairs must be carried out immediately they become necessary.

The maintenance work on a crossing will include the following:—

Bridges. Repairs to or replacement of leaky boats, broken superstructure, adjustment of cables and anchors, and, where necessary, under the direction of the G.S.O. in charge, the working of cuts in a bridge. The provision of sand, straw or hay to give foothold to animals, and clearing flotsam and jetsam or any other floating object which may affect the safety of the bridge.

Ferries. Repairs to landings and boats, the provision of suitable fenders. Overhaul of cables and anchors of flying bridges.

Fords. Removal of stones and boulders from the bottom, filling holes, and marking the direction so clearly that no one can miss their way day or night. Stones and boulders should be moved to the up-stream side of a ford. If placed down steam they tend to increase the depth of the ford, and form another danger to those men and animals who have wandered from the proper track through their natural inclination to go down stream.

Approaches. It is most probable that the approaches to all crossings will call for a greater degree of maintenance than the bridge itself, and these must be very carefully watched from the beginning, and repaired as soon as they show any signs of failing. The approaches of a heavy pontoon bridge when used by mechanical transport require special and constant attention.

One of the most difficult problems to cope with is the pull out on the far side of the ford. Unless this receives constant attention, it will quickly become very difficult from the water dripping from men's clothes and animals, and forming water courses.

A light covering of reeds, grass, straw or sand and grit will often enable animals to gain foothold, and wheels to bite on slippery surfaces.

Round boulders from a river bed must be broken before they will form useful material for mending roads.

Section XVI.—SPECIAL USE OF SPARS.

Field observatories.

1. The use of captive balloons and the improvements in aircraft have very much diminished the importance of high field observatories.

The construction of an observatory over 50 feet high would be seldom desirable, owing to its visibility and consequent power of drawing artillery fire on itself and the troops in the vicinity.

Field observatories up to the height of 50 feet are, on the other hand, likely to retain their importance, especially in close country; but they must always be carefully concealed if there is any risk of betraying the presence of the force.

Against an uncivilized enemy in thick bush country a single spar carried with the column and set up temporarily at intervals as an observatory has been successfully employed to prevent surprise attacks on the columns while on the march.

General considerations.

2. In connection with any improvised observatory, the following points will generally have to be considered :—

(1) The provision of a platform large enough to accommodate the observer and his telescope.

(2) The method of obtaining the required height by means of spars, trees, scaffolding, steel masts, &c.

(3) The method of making and raising the observatory.

(4) The means by which the observer reaches the platform, being by ladders, cleats, or block and tackle.

Types of observatories.

3. The following types of field observatories will generally be found best for the different heights required :—

Up to 40 or 50 feet	Trees, single spars, tripods of spars or ladders.
Up to 100 or 120 feet ...	Scaffolding, composite spars.
Over 120 feet	Composite spars raised to the head of a tripod. Steel or girder masts, such as are often used in wireless installations.

4. A very little labour and few stores will make an excellent observatory in a tree. It may have to be guyed to prevent it swinging, and trimmed of superfluous branches to obtain a good view. It has the advantage that at a distance it is not easily recognized as an observatory, but the height obtained will often not be sufficient. **Tree observatory.**

5. A tripod observatory (Pl. XCI., Fig. 1) is steadier than one made of a single spar. The legs may be spars or ladders; if scaling ladders are used, 12-ft. ladders are the best as they stand without stiffening, which is not the case with 6-ft. ladders. Sufficient lengths of tips should be left above the crutch to form a platform 8 to 10 feet wide. **Tripod observatory.**

6. The tripod can be made and raised in a similar manner to that in which a gyn is constructed; another method is to lash two of the legs together on the ground as sheers, and raise them by using the third leg as a derrick. After getting the feet into position, the third leg is lowered into the fork of the sheers and lashed. **Erection of tripod observatories.**

7. An observatory of scaffolding was constructed on the James River in the American Civil War (Pl. XCII., Fig. 2). A rather simpler type is shown in Fig. 1; it may be found to require guying to steady it in the wind. **Scaffolding observatory.**

8. A single composite spar (Pl. XCI., Fig. 2) is more quickly and economically made. The spars must be arranged to break joint throughout, should be lashed every 5 feet, and the lashings wedged up. In making a composite spar it should be borne in mind that the greatest strain will occur in raising it, and that, therefore, the bottom should rarely consist of a single spar. To raise a composite spar of 100 feet length, a pair of 60-ft. sheers and a capstan are necessary. The main tackle from the sheers should be fastened at a point "A" (Fig. 3) about two-thirds up the spar or else to the bridle X Y Z, the latter having the disadvantage of bringing the main tackle chock-a-block before the spar is vertical. The sheers should be set slightly back at starting, to avoid subsequent hauling on the sheer guys. The fore guy of the main spar must be passed through the snatch block "B," near the tip of the sheers. The snatch of the block should be left open to allow of the guy being jerked clear, as soon as it has assumed the position D B E. A smooth round spar lashed across the head of the sheers and well soaped answers instead of a snatch block. **Composite spar.**

The spar must have a double set of four guys, the upper set fastened just below the platform, the lower a little more than half way up (Fig 2).

9. Another method of gaining considerable height is to raise two or three single spars one above the other (Pl. XCII., Fig. 3), each spar being separately guyed. This method, though economical of timber, is not so steady as a single composite spar. **Three-spar observatories.**

10. The observatory shown on Pls. XCIII., XCIV., XCV. was erected on Salisbury Plain and although not strictly speaking a **Framed observatory.**

field observatory still it gives a very good idea how such a structure may be put together and erected from timber not exceeding 26 feet long.

The observatory was first of all constructed on the ground at the workshops where it was made, each timher being carefully fitted into its place and marked. It was then taken to pieces and erected on the selected site in the following manner:—

Two legs C D and one side were built into a frame on the ground, and erected by means of derricks and tackles in the usual way. Prior to being raised two frames X Y were bolted to the top of each of the legs C D.

The lower sections of legs A and B were then built into a frame, raised into position and the lower frame of the whole structure was completed. The remaining timbers of the structure were severally raised to their approximate positions by tackles fixed to the frames X and Y which acted as jib cranes.

BUOYANCY OF BOATS.

Fig. 1.

Fig. 2.

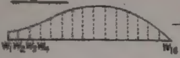


Fig. 3.

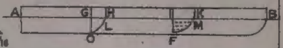
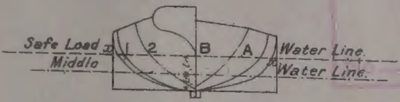
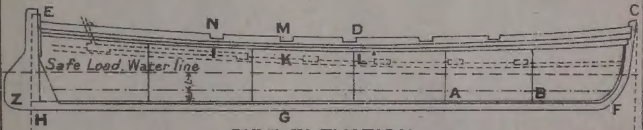


Fig. 4.



ELEVATION OF HALF SECTIONS.

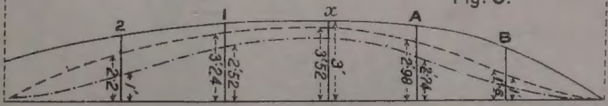
Fig. 5.



SIDE ELEVATION.

STIRLING'S RULES Nº 1.

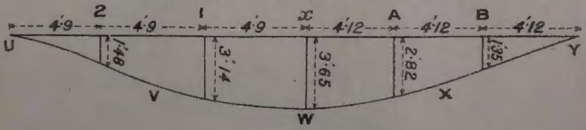
Fig. 6.



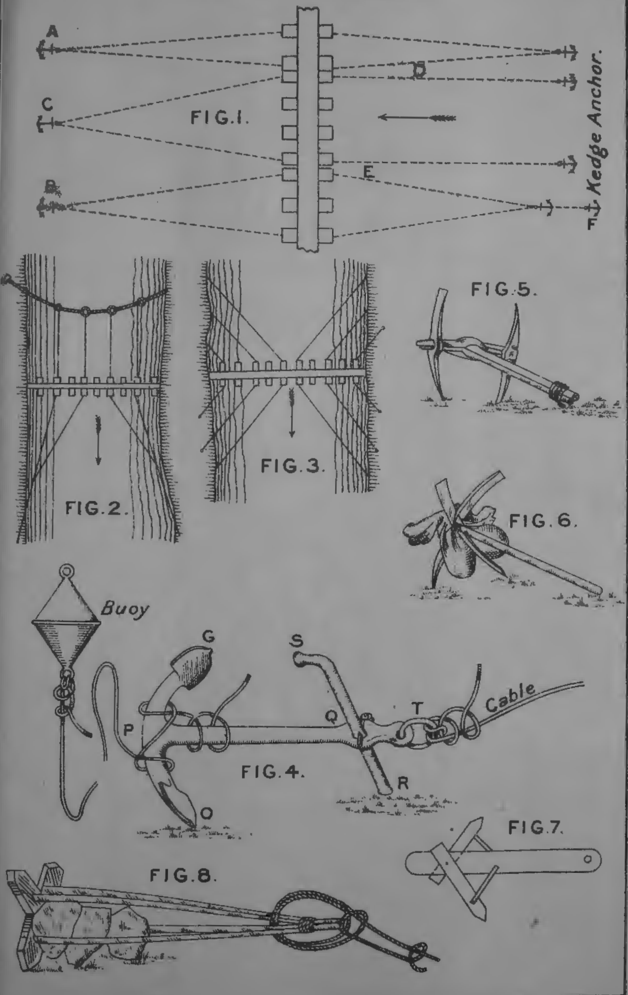
HALF PLAN.

STIRLING'S RULES Nº 2.

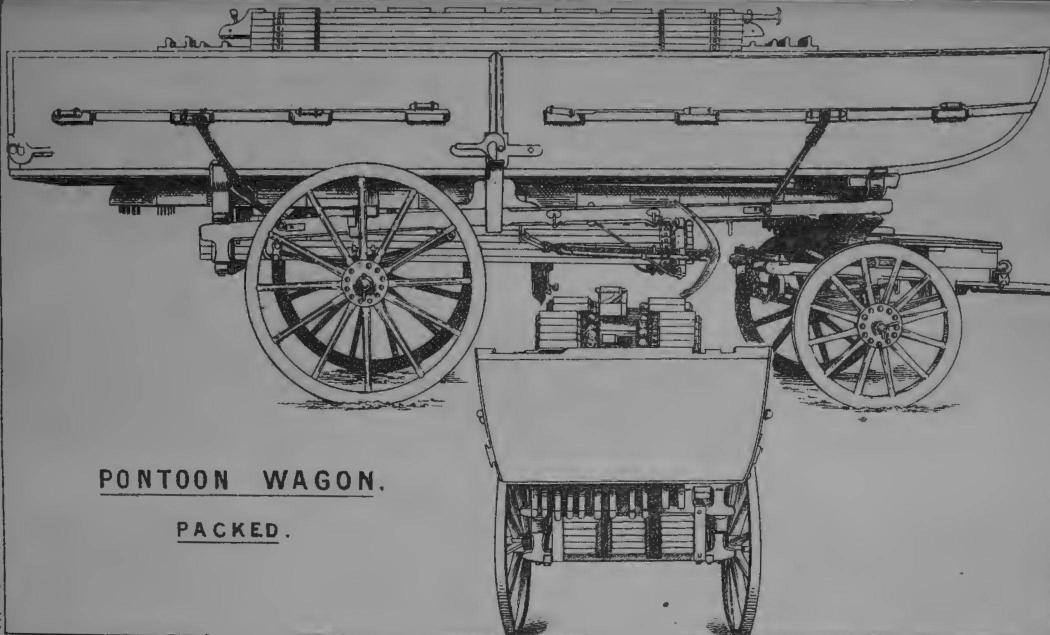
Fig. 7.



ANCHORAGES, &c.



Malby&Sons.Lith

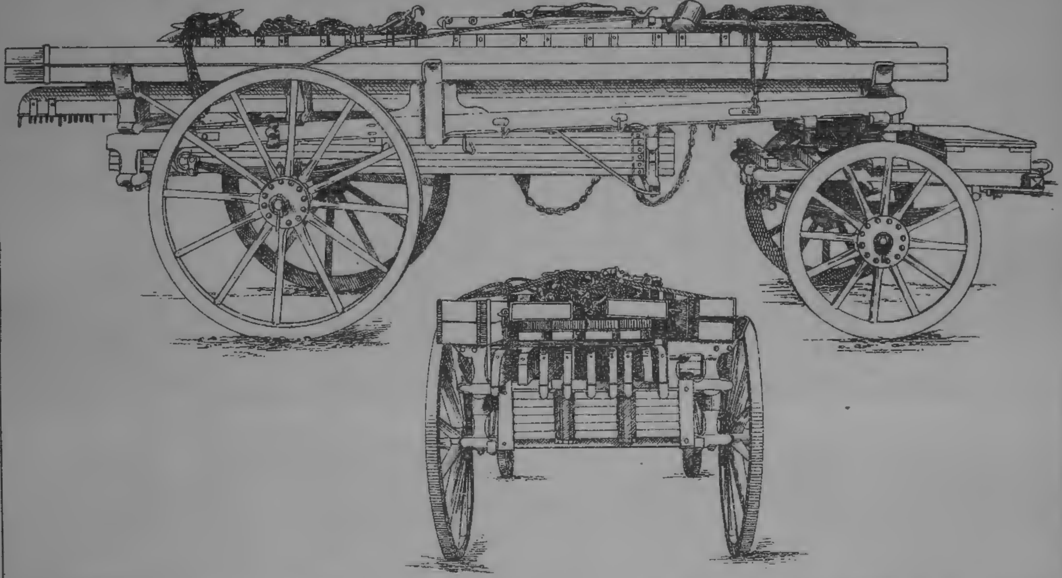


PONTOON WAGON.

PACKED.

Malby & Sons, Lith.

SERVICE TRESTLE, PACKED.



Malby & Sons, Lith

Plate IV.

PONTOON SUPERSTRUCTURE.

FIG. 1. PLAIN BAULK.

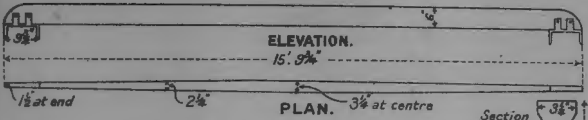


FIG. 2. BUTTON BAULK.

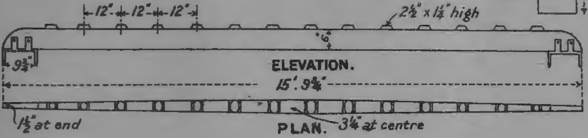


FIG. 3. RIBAND.

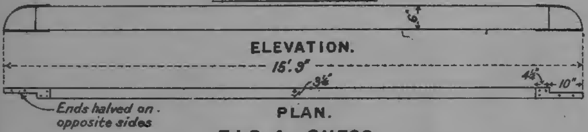


FIG. 4. CHESS

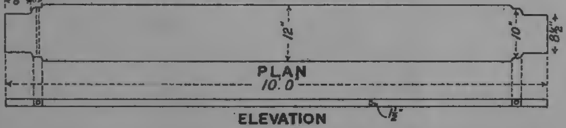


FIG. 5. SADDLE BEAM.

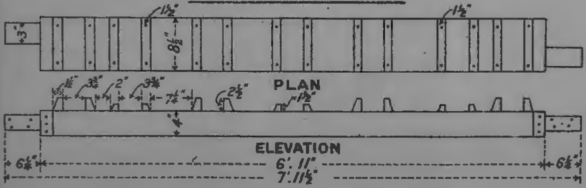
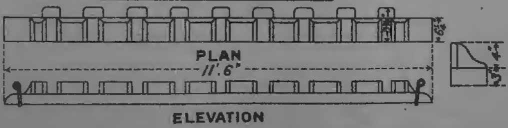


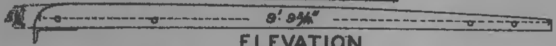
FIG. 6. SHORE TRANSOM.



Malby & Sons, Lith.

FIG. I.

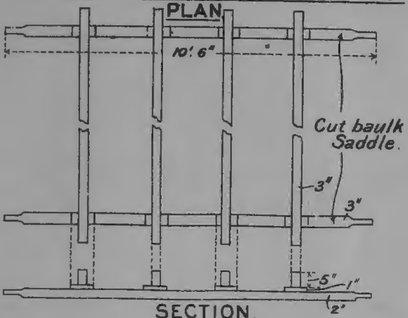
CUT BAULK.



ELEVATION.

FIG. 2.

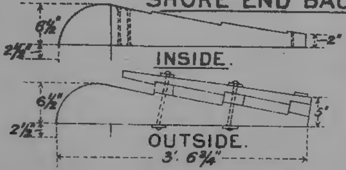
SET OF CUT BAULKS.



SECTION.

FIG. 3.

SHORE END BAULKS.



LIGHT BRIDGE.

FIG. 4.

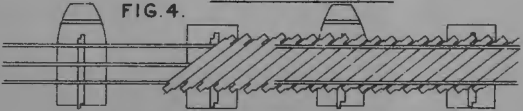


FIG. 5.

MEDIUM BRIDGE.

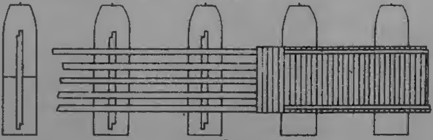
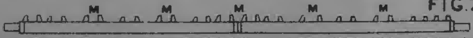


FIG. 6.

ELEVATION OF SADDLE BEAM SHOWING CLEATS USED FOR LIGHT BRIDGE.

FIG. 7.



ELEVATION OF SADDLE BEAM SHOWING CLEATS USED FOR MEDIUM BRIDGE.

Malby & Sons Lith

BRIDGING TRESTLE.

FIG. 1.

FRONT ELEVATION.

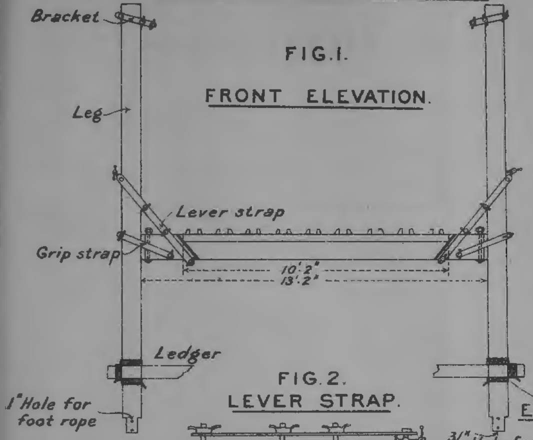


FIG. 2.

LEVER STRAP.

SIDE ELEVATION.

FIG. 3.

GRIP STRAP.

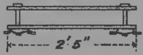


FIG. 4.

GRIP STRAP UP.

(Trestle fixed)

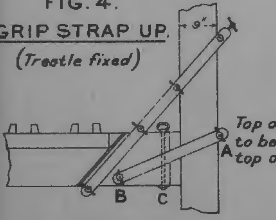


FIG. 5.

DIFFERENTIAL TACKLE.

GRIP STRAP HORIZONTAL.

(For adjusting transom.)

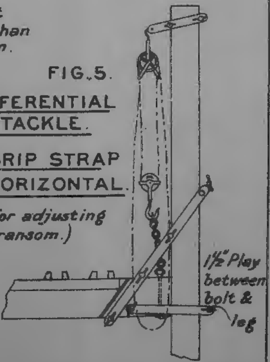
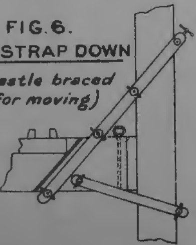


FIG. 6.

GRIP STRAP DOWN

(Trestle braced for moving)



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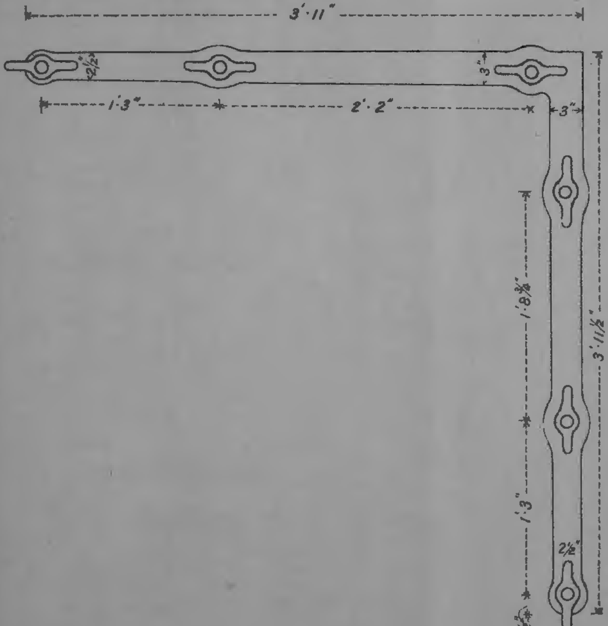
IMPROVED LEVER STRAP.

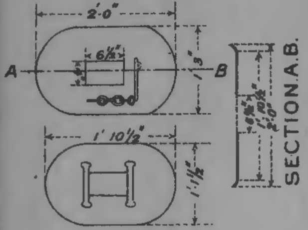


BRIDGING TRESTLE.

FIG. 7.

STEEL SHOE.

Underside of Shoe.



Top of Shoe.

FIG. 8.

BEARING PLATES.

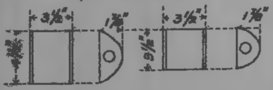
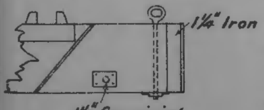
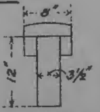


FIG. 9.

FIG. 10.

TRANSOM END.





SECTION.

FIG. 11.

BRACKET.

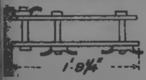


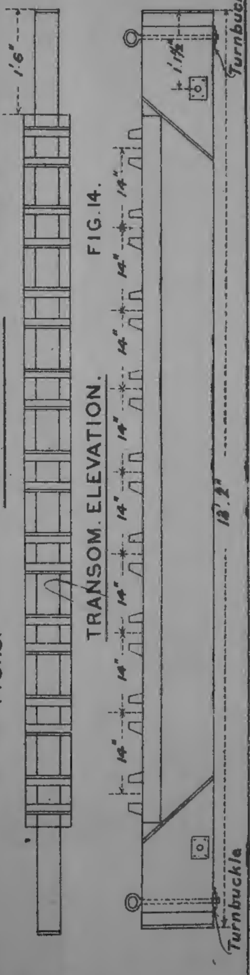
FIG. 12.

FIG. 13.

TRANSOM. PLAN.

FIG. 14.

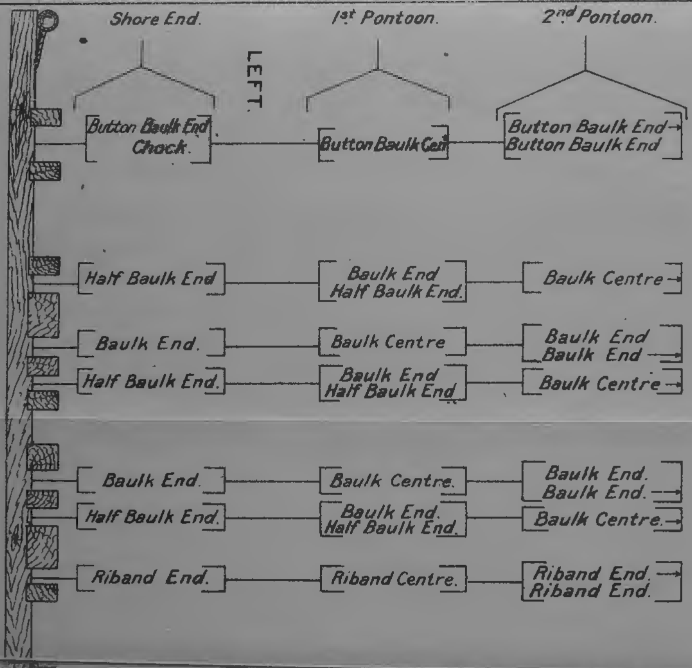
TRANSOM. ELEVATION.



Malby & Sons, Lith

DIAGRAM TO SHOW ARRANGEMENT O…
AND TWO FIRST PON…

NOTE:- Baulks etc. marked ——→ at Seco…



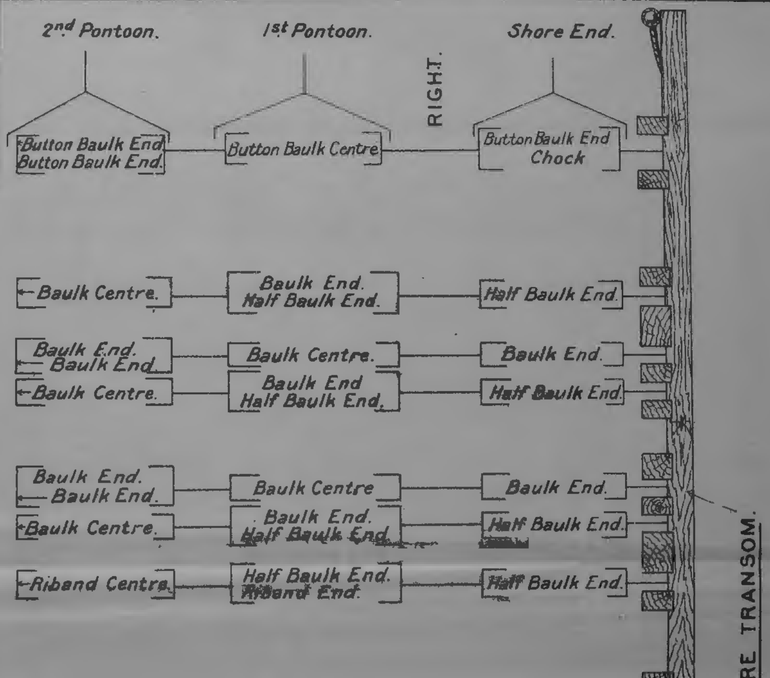
PROVISIONA…

Plate X.

...AULKS ON SADDLE OF SHORE END

...IS OF HEAVY BRIDGE.

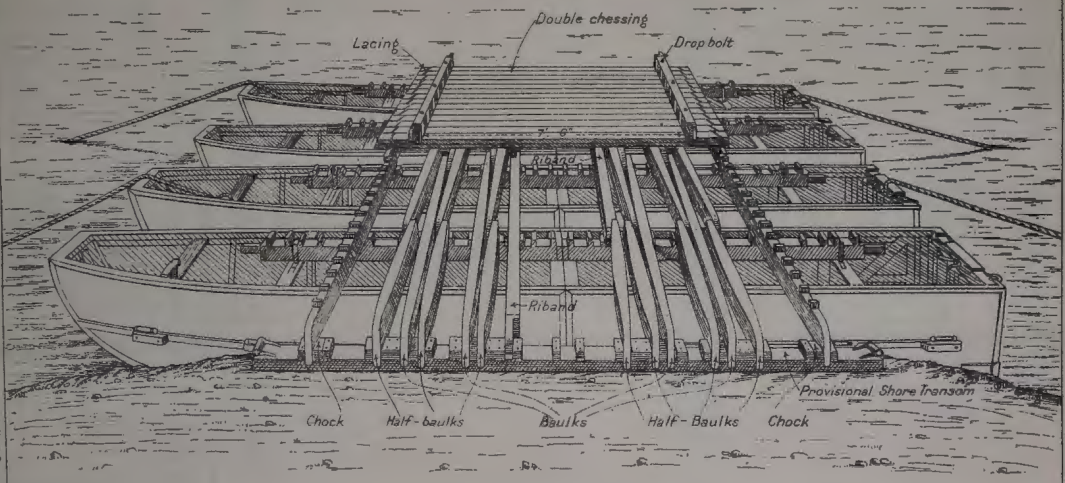
...toon continue over next Bay of the Bridge.



Malby & Sons, Lith

HEAVY PONTOON BRIDGE FOR MECHANICAL TRANSPORT

(showing arrangement of baulks and chessing.)

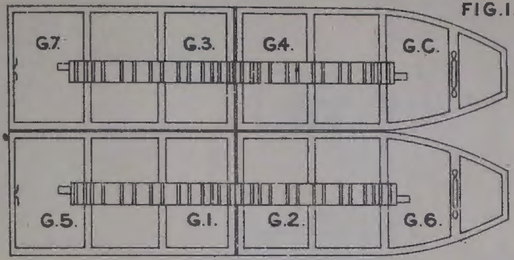


Malby & Sons. Lith

Plate XI.

POSITIONS OF "G" DETACHMENT IN FORMING UP HEAVY BRIDGE.

FIG. I.



RIBANDS AS WHEEL GUIDES HEED BY 3 BOLTS DROPPED THRO' HOLES.

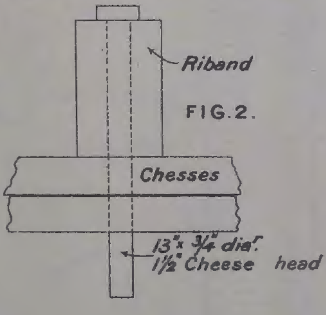
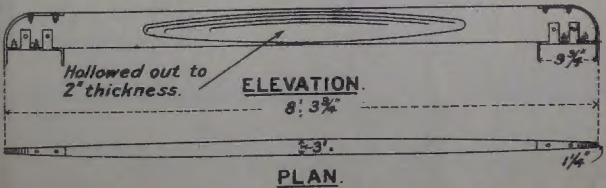


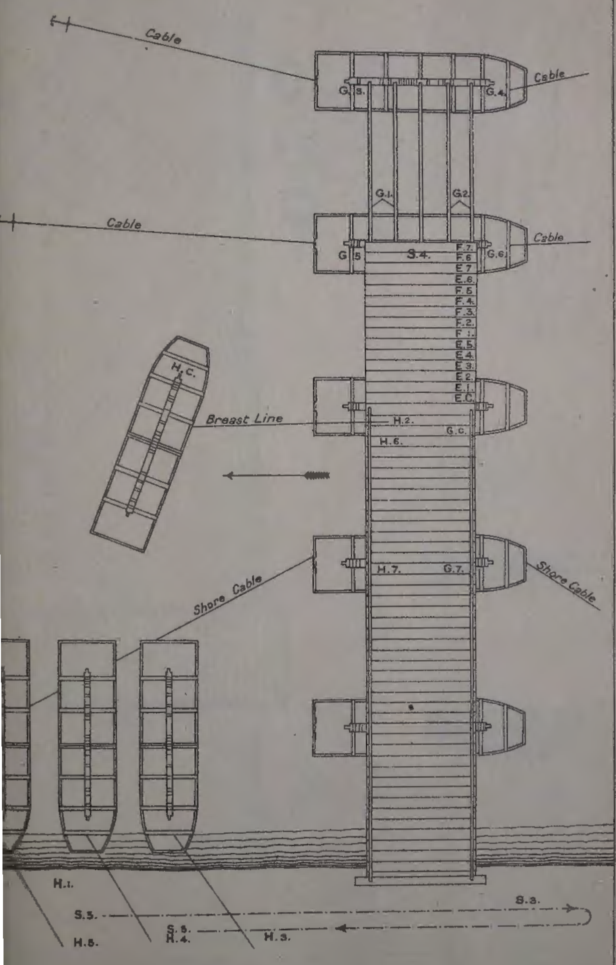
FIG. 3.

DESIGN FOR HALF BAULK HEAVY BRIDGE.



Malby & Sons, Lith.

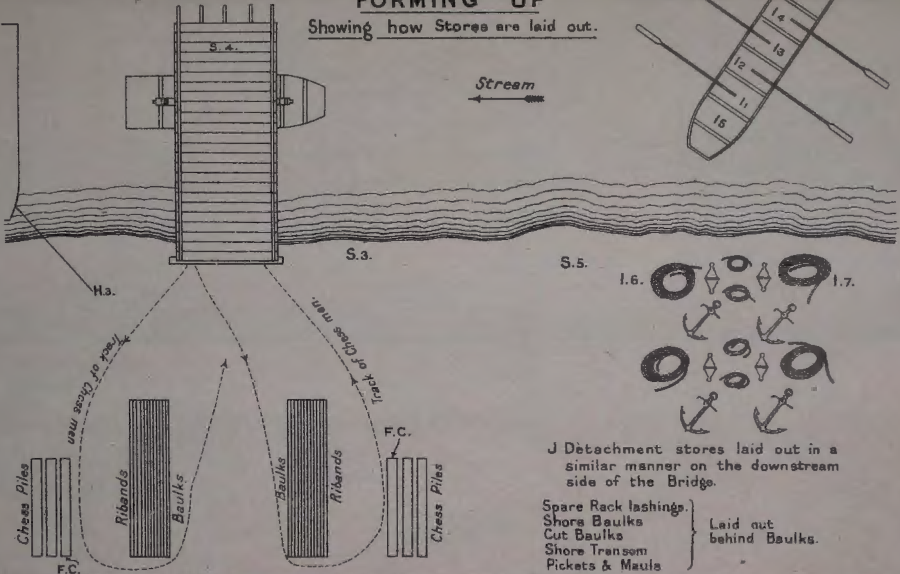
FORMING UP "CHESSES".



Malby & Sons, Lith.

FORMING UP

Showing how Stores are laid out.



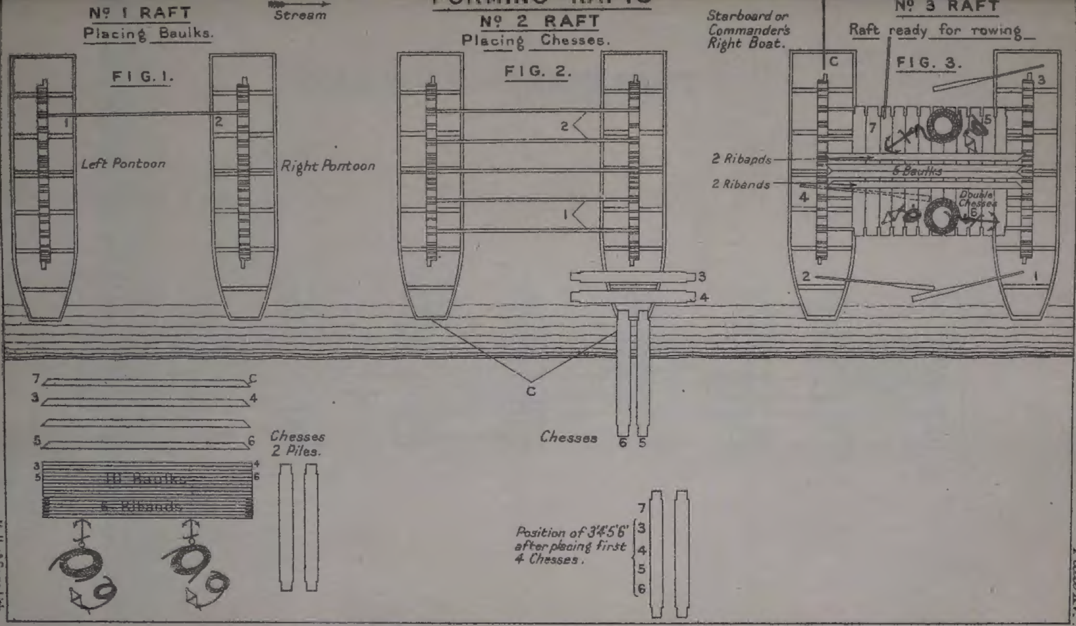
J Detachment stores laid out in a similar manner on the downstream side of the Bridge.

Spare Rack lashings.
Shore Baulks
Cut Baulks
Shore Transom
Pickets & Mauls

} Laid out behind Baulks.

Malby & Sons Lith.

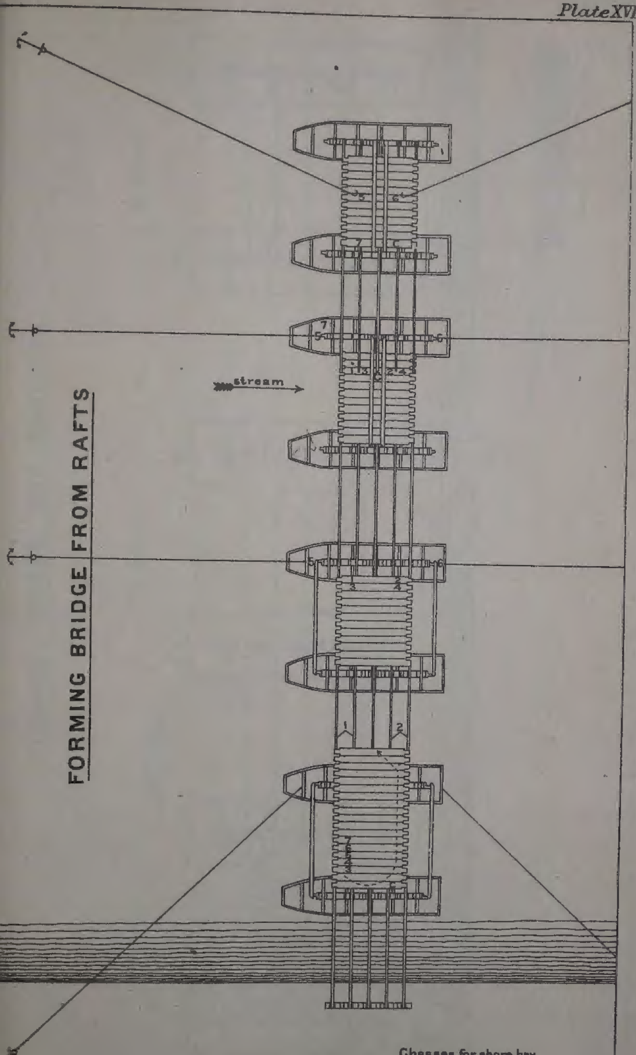
Plate XIV.



Melby & Sons Lith.

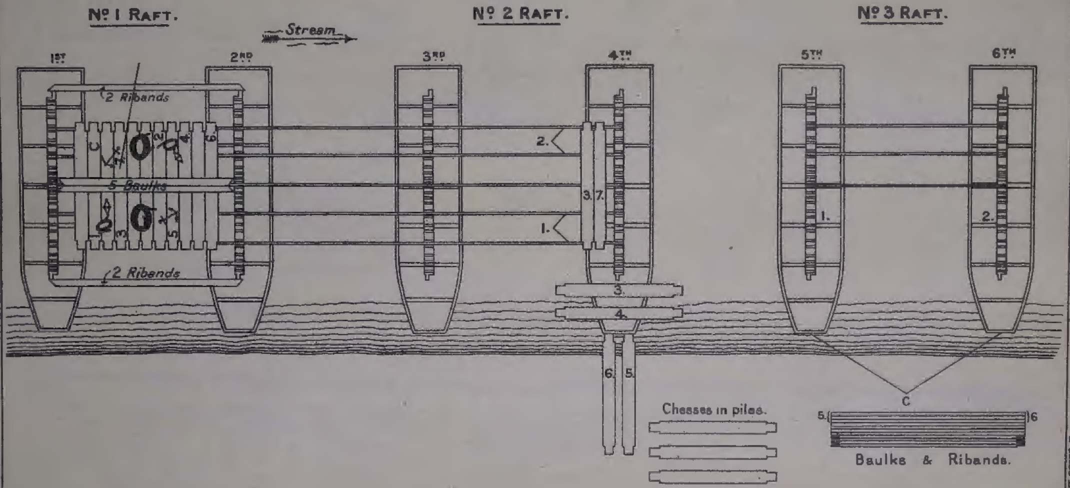
Plate XV.

FORMING BRIDGE FROM RAFTS



Malby & Sons, Lith.

FORMING BRIDGE FOR SWINGING.



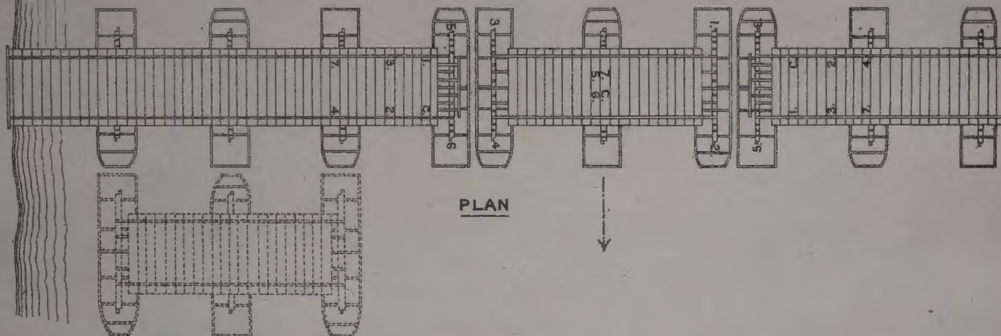
Maulby & Sons. Lith.

Plate XVII.

PONTOON BRIDGES

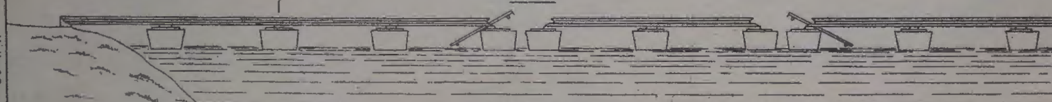
FORMING SINGLE CUT.

FIG. 1.



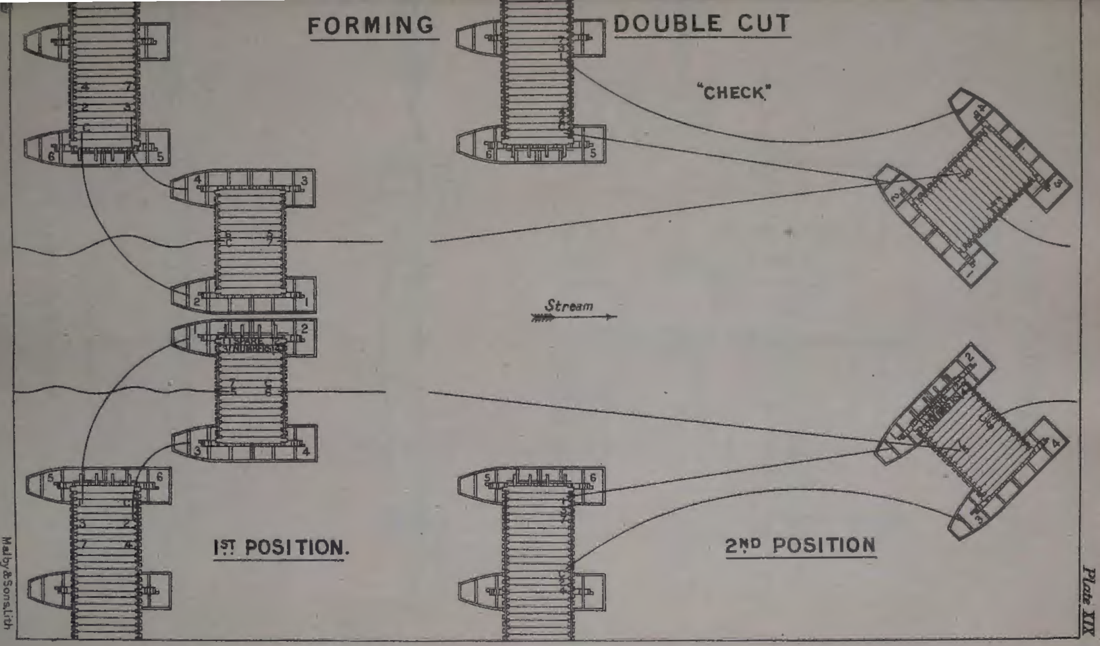
PLAN

FIG. 2.



ELEVATION.

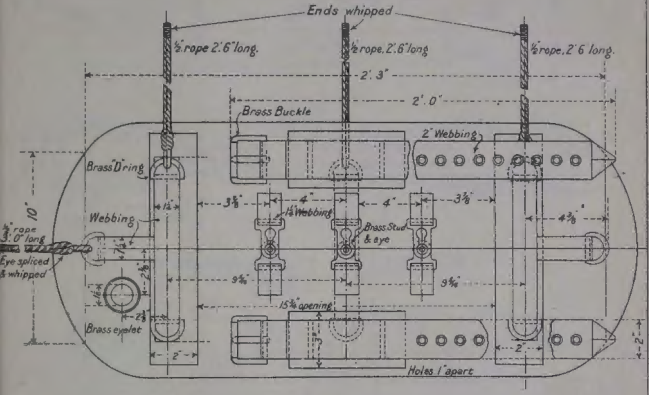
Malby & Sons, Lith.



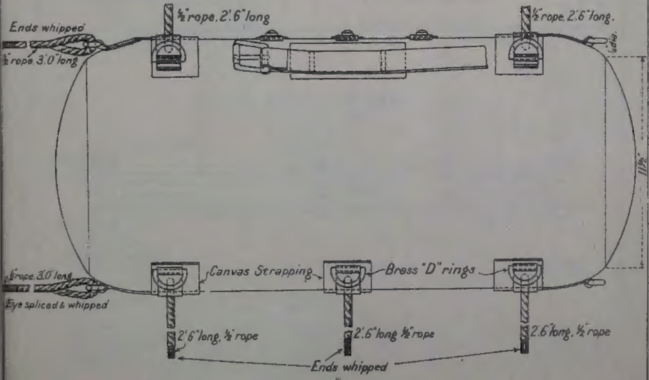
FORMING DOUBLE CUT
"CHECK"
Stream
1ST POSITION.
2ND POSITION
Malby & Sons Lith
Plate XIX

AIR RAFT EQUIPMENT

BAGS. OUTER CANVAS.



PLAN



SIDE ELEVATION

AIR RAFT EQUIPMENT.

WHEELWAY – RAFT SECTION "A"

FIG. 1.

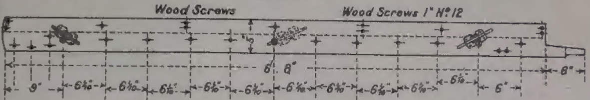
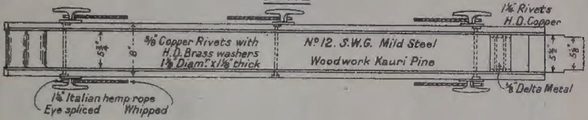


FIG. 2



WHEELWAY – RAFT SECTION "B"

FIG. 3.

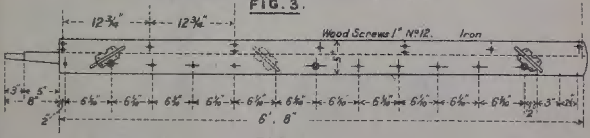
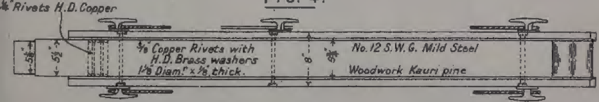


FIG. 4.



WHEELWAY – SHORE

FIG. 5.

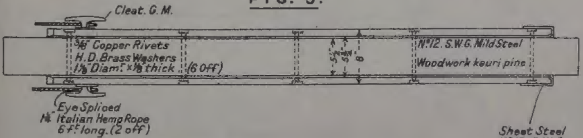
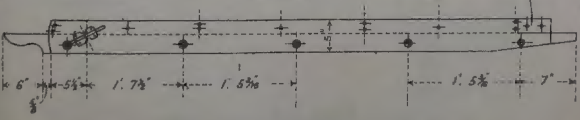


FIG. 6.



AIR RAFT EQUIPMENT.

FIG. 1.

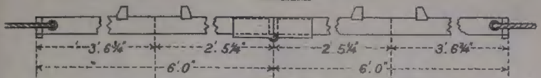
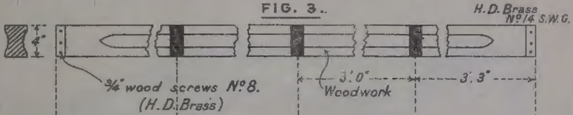


FIG. 2.

BAULK, SADDLE, HINGED

FIG. 3.



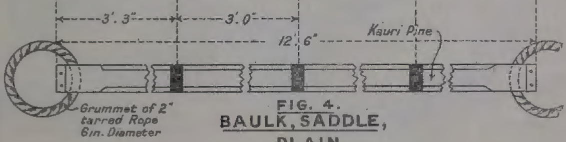


FIG. 4.

BAULK, SADDLE, PLAIN

FIG. 5.

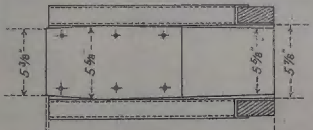


FIG. 6.

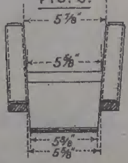


FIG. 7.

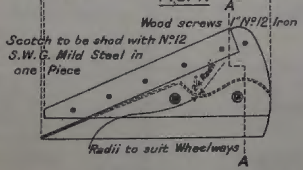
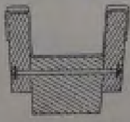


FIG. 8.



SECTION A.A.

WHEELWAY, SHORE, SCOTCH.

LIGHT RAFT EQUIPMENT.

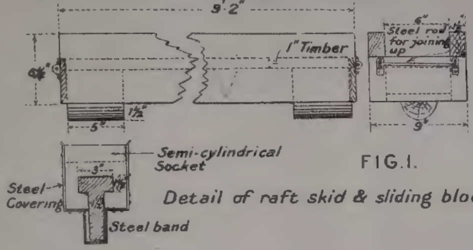


FIG. 1.

Detail of raft skid & sliding block

FIG 2

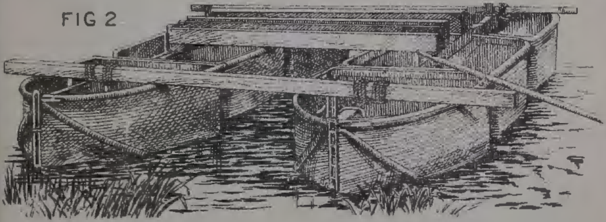
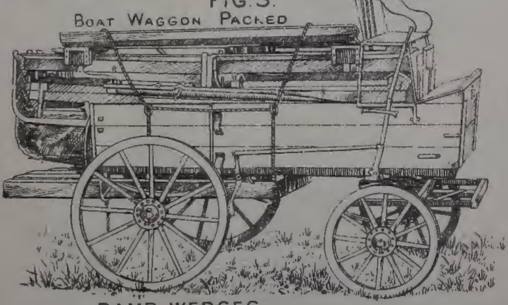


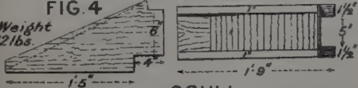
FIG. 3.

BOAT WAGGON PACKED



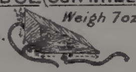
RAMP, WEDGES.

FIG. 4



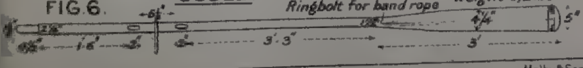
WEDGE (GUN WHEELS)

FIG. 5.



SCULL.

FIG. 6.



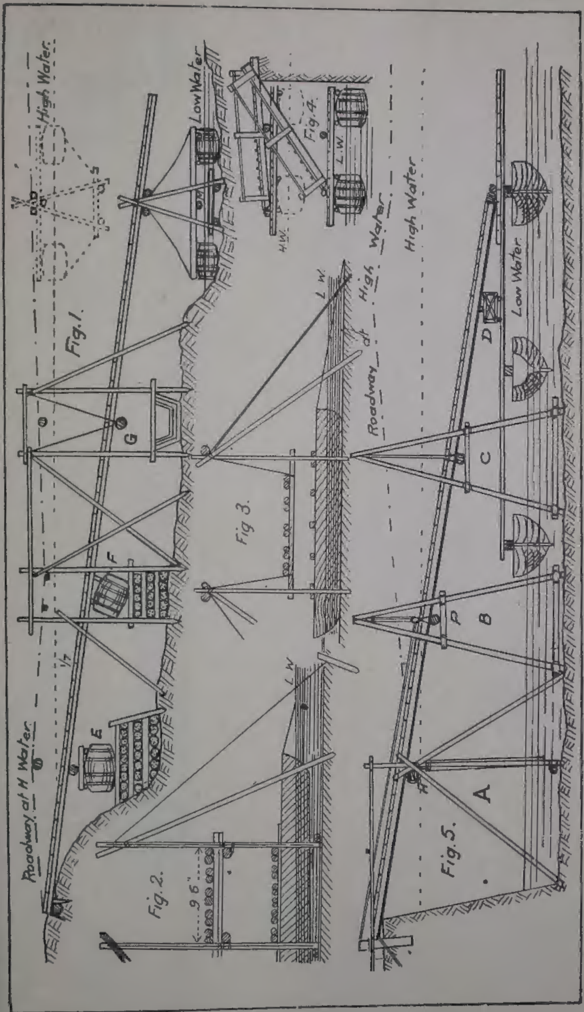


Fig.1.
Roadway at H Water.
High Water.
Low Water
E
F
G
Fig.2.
9' 6"
L.W.
Fig 3.
Fig.4.
H.W.
L.W.
Roadway at High Water
High Water
Fig.5.
A
B
C
D
Low Water.

TIDAL RAMPS OF PONTOON EQUIPMENT.

FIG. I.

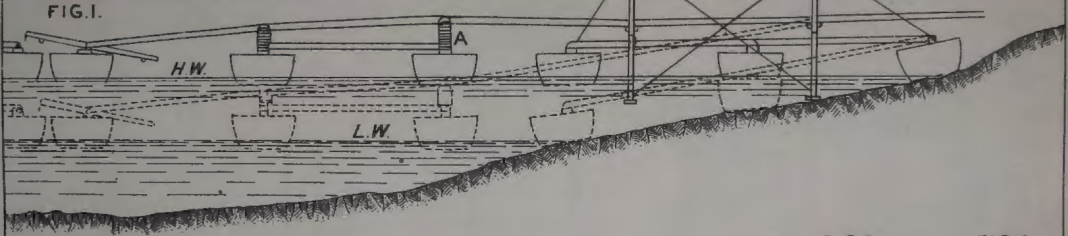


FIG. 2.

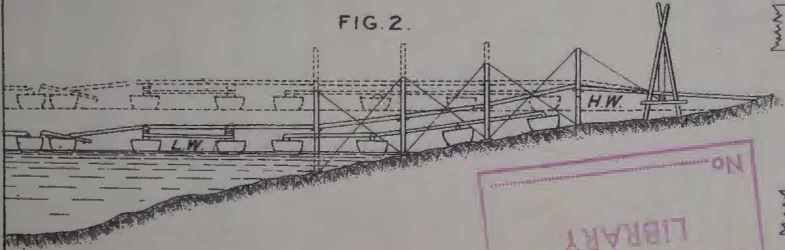


FIG. 3.
SECTION AT A.
(FIG. I.)

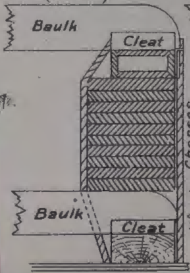


FIG. 4.
ELEVATION AT A.
(FIG. I.)

Plate XXVII.

Malby & Sons, Lith.

LIFT FOR VEHICLES FOR USE IN TIDAL WATER.

FIG. 1

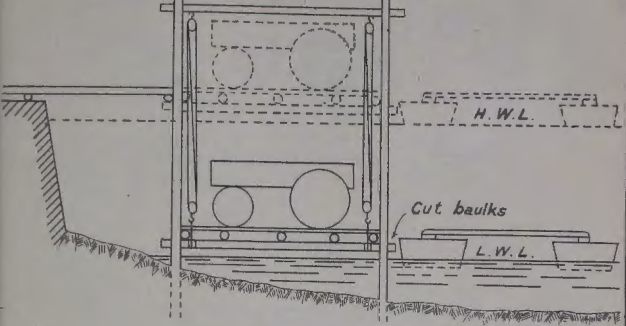


FIG. 2.

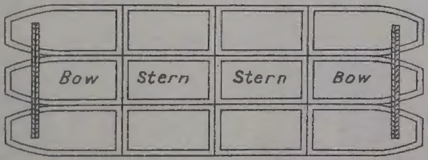
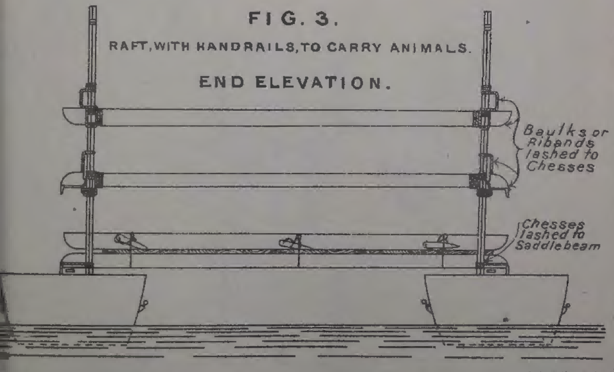


FIG. 3.

RAFT, WITH HANDRAILS, TO CARRY ANIMALS.

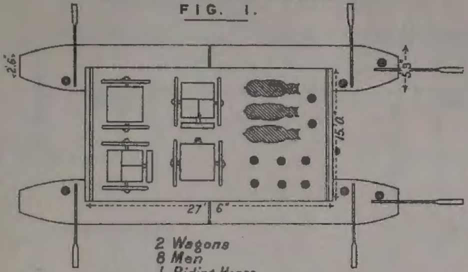
END ELEVATION.



Malby & Sons Lith.

4 PONTOON RAFT

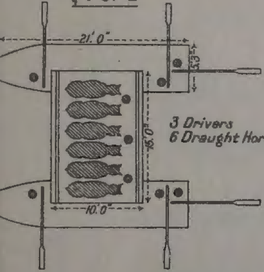
FIG. 1.



2 Wagons
8 Men
1 Riding Horse
2 Draught Horses

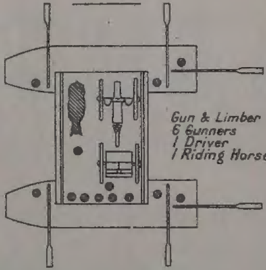
2 PONTOON RAFTS

FIG. 2



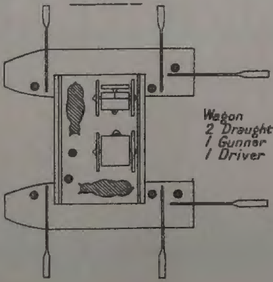
3 Drivers
6 Draught Horses

FIG. 3.



Gun & Limber
6 Gunners
1 Driver
1 Riding Horse

FIG. 4.



Wagon
2 Draught Horses
1 Gunner
1 Driver

Malby & Sons, Lith.

RAFT FOR 60 P^R B.L. GUN

FIG. I.

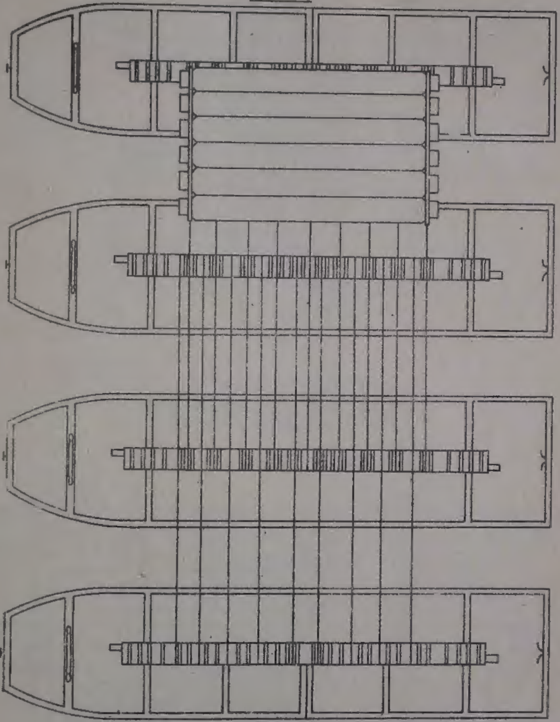
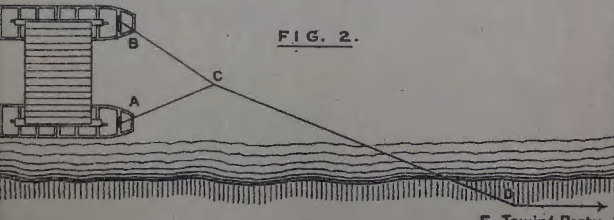


FIG. 2.



Malby & Sons, Lith.

PIER HEADS.

Fig. 1.

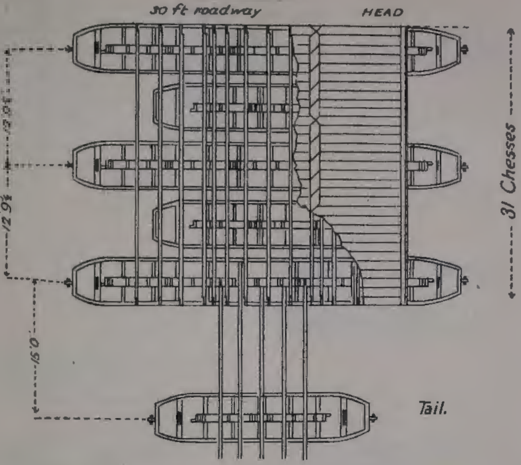
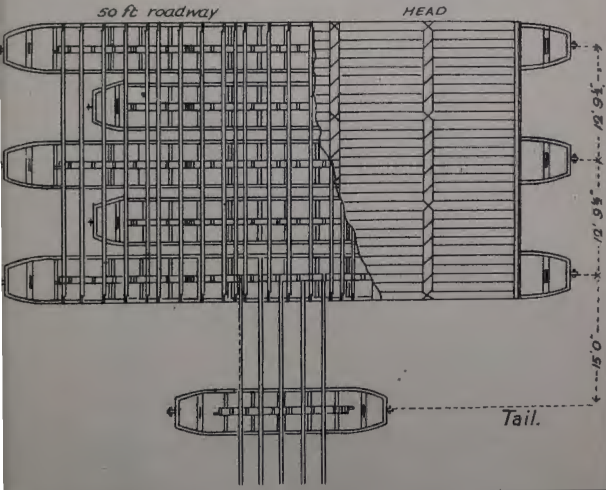


Fig. 2.



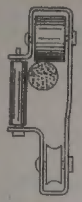


FIG. 1.

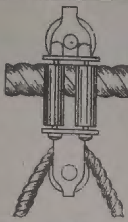


FIG. 2.

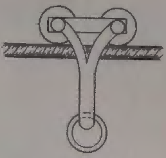
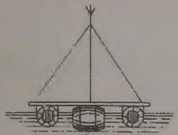


FIG. 3.

FIG. 4.



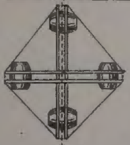


FIG. 5.

FIG. 6.

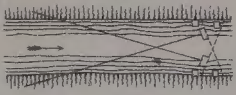


FIG. 7.

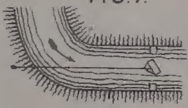


FIG. 8.

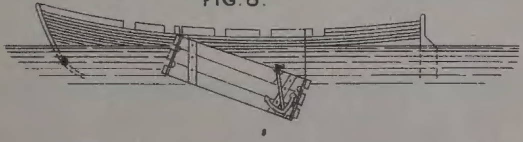
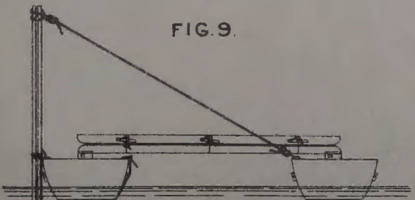
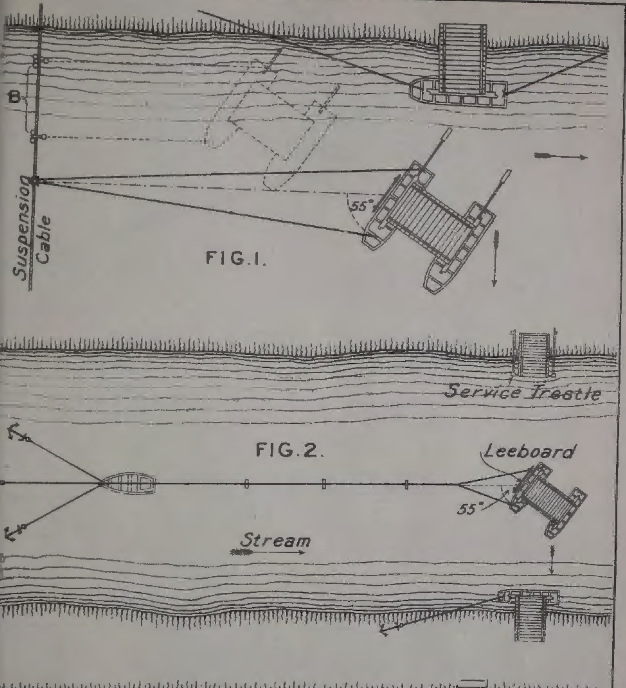


FIG. 9.



Malby & Sons, Lith.

Plate XXXIII.



Malby & Sons, Lith.

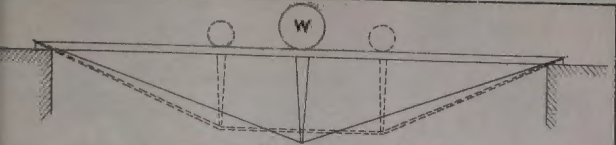


FIG. 1. TRUSSED BEAM.

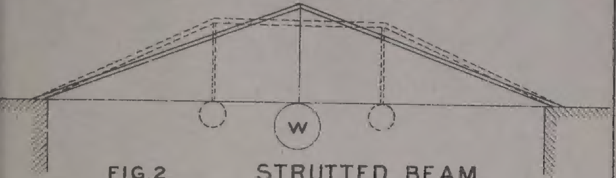


FIG. 2 STRUTTED BEAM.

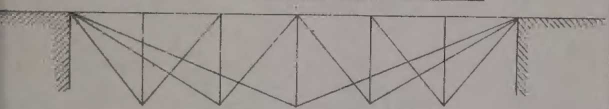


FIG 3. FINK TRUSS.

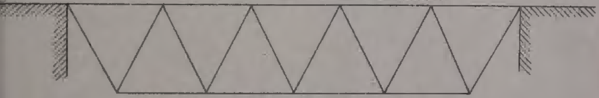


FIG. 4. WARREN GIRDER.

FIG. 5. LATTICE GIRDER.

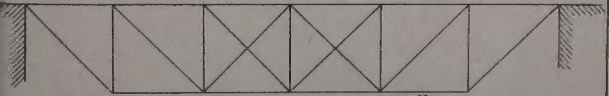


FIG. 6. "N" GIRDERS.

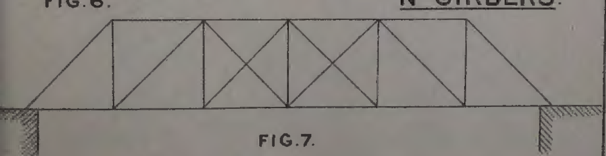


FIG. 7.

Malby & Sons, Lith.

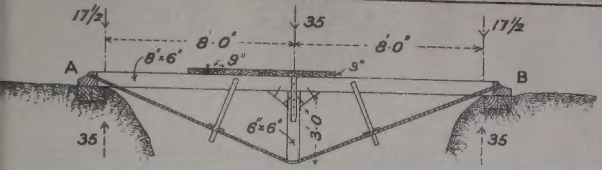


FIG. 1.

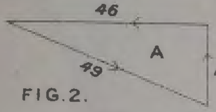


FIG. 2.

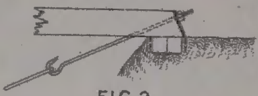


FIG. 3.

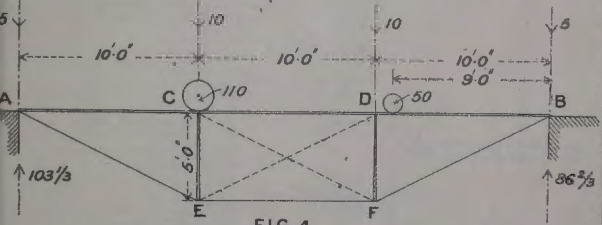


FIG. 4.

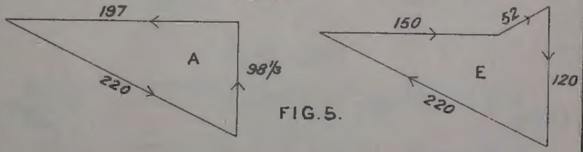
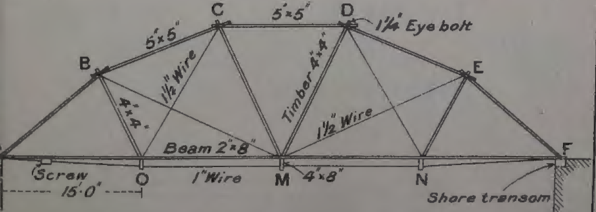


FIG. 5.

FIG. 6.



Melby & Sons, Lith.

GIRDERS

ELEVATION

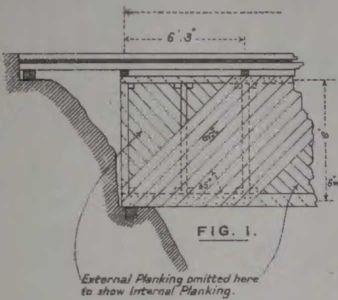


FIG. 1.

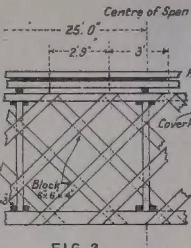


FIG. 2.

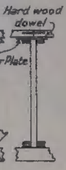


FIG. 3.

SECTION.

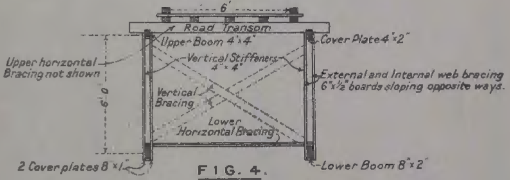


FIG. 4.

ELEVATION

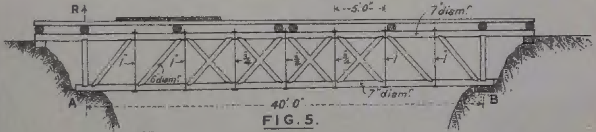


FIG. 5.

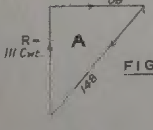
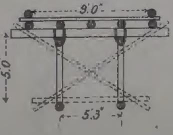


FIG. 6.



SECTION
FIG. 7.

Malby & Sons, Lith.

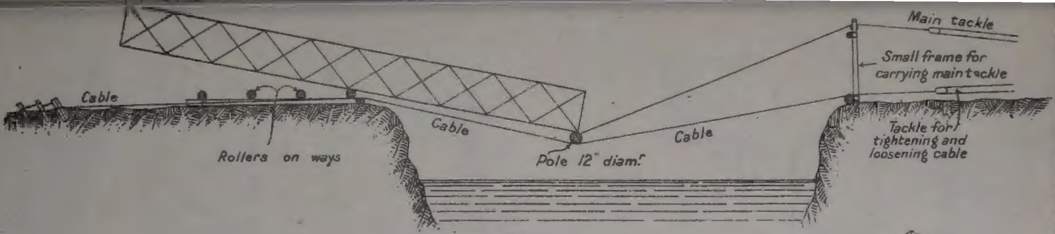


FIG 1.

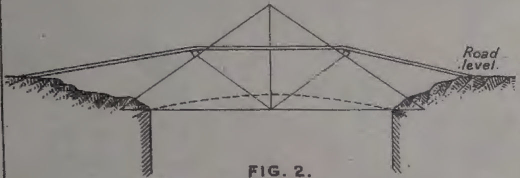


FIG. 2.

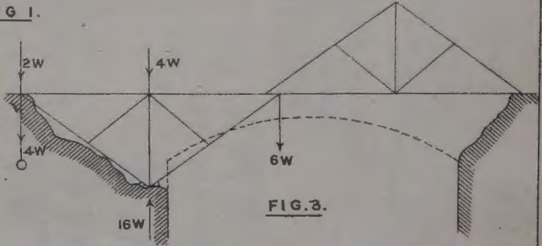
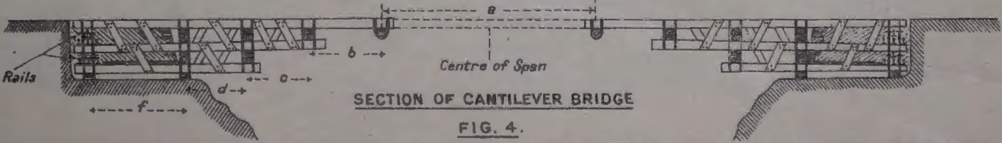


FIG. 3.



SECTION OF CANTILEVER BRIDGE

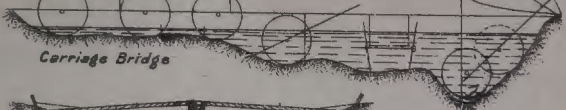
FIG. 4.

Malby & Sons Lith.

Plate XXXVII.

SUBSTITUTES FOR TRESTLES.

FIG. I.



Carriage Bridge

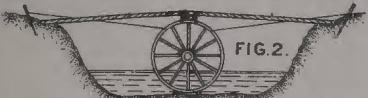


FIG. 2.

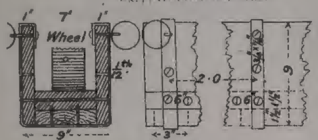


FIG. 3.

Gun wheel Troughs for 18 Pr. B.L. 18 ft. spans.
Length 20 ft. weight of each 130 lbs.
To be reversed for men. Ends to be lashed to pickets and bedded in earth banks.

FIG. 4.

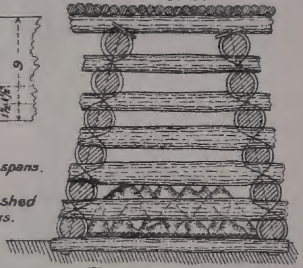


FIG. 5.

FIG. 6.

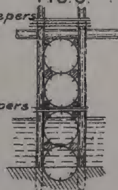
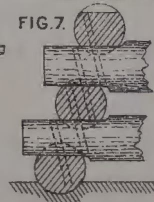


FIG. 7.



Crib work with trenail fastenings instead of Rope and Creepers as in Fig. 4.

FIG. 8.

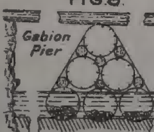


FIG. 9.

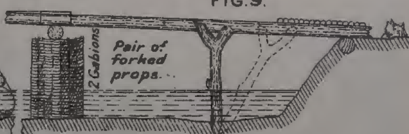


FIG. 10.

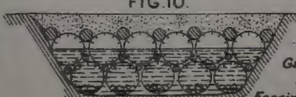
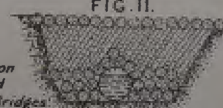


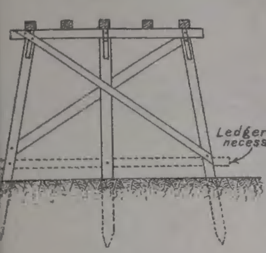
FIG. 11.

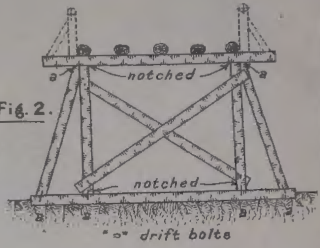


Gabion and Fascine Bridges.

TRESTLES.

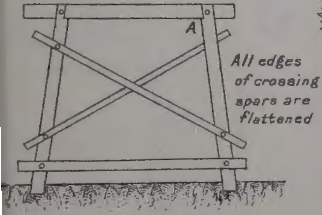
Fig. 1.





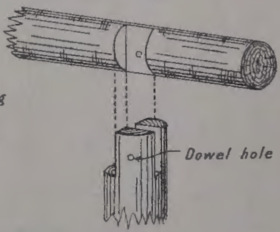
Spar Trestle with dowels.

Fig. 3.



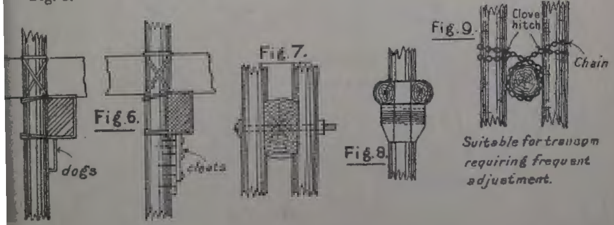
Detail at "A."

Fig. 4.



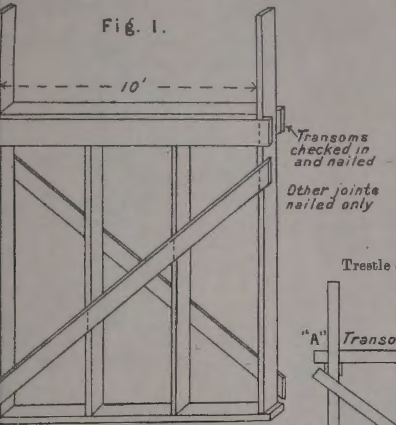
Other Methods of Fastening Transoms.

Fig. 5.

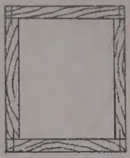


TRESTLES.

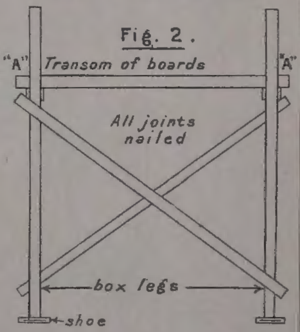
Plank Trestle (Perspective).



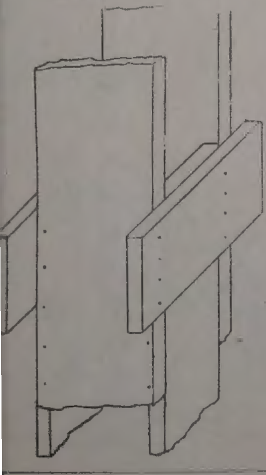
Section of Leg in Fig. 2.



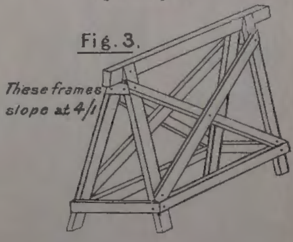
Trestle of Floor Boards 7″ × 1″.



Detail at "A." Fig. 2.



Four-legged Trestle of Rectangular Timber Spiked together.



HEAVY ROAD BRIDGE

FIG. 1.

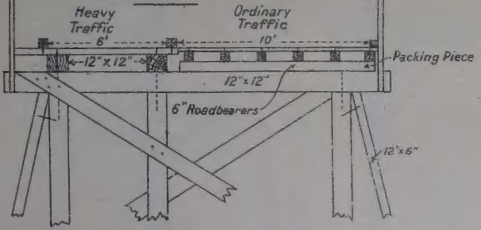
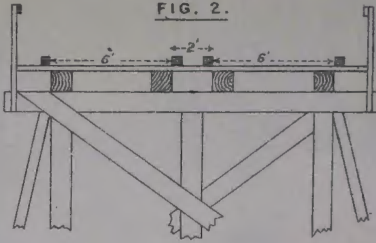
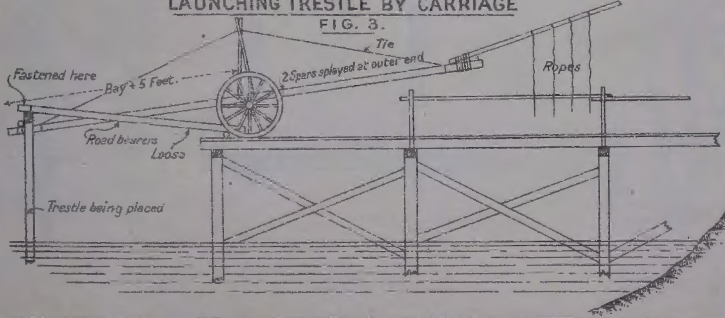


FIG. 2.



LAUNCHING TRESTLE BY CARRIAGE

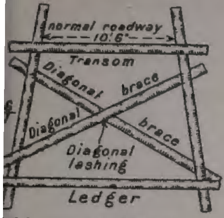
FIG. 3.



Malby & Sons, Lith.

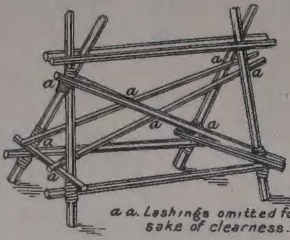
Plate XII.

Fig. 1.



All junctions lashed with wire or rope, square lashings except where stated.

Fig. 2.



a a. Lashings omitted for sake of clearness.

Fig. 3.

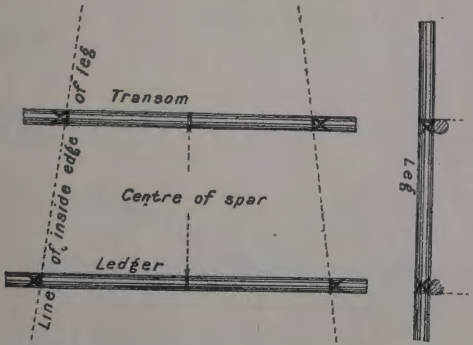
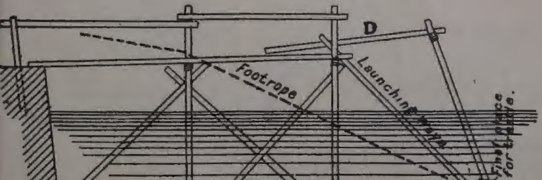


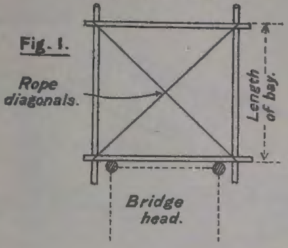
Fig. 4.



RAISING HEAVY TRESTLE BY DISTANCE FRAME.

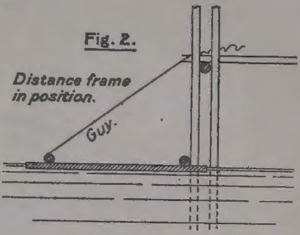
Plan of distance frame.

Fig. 1.



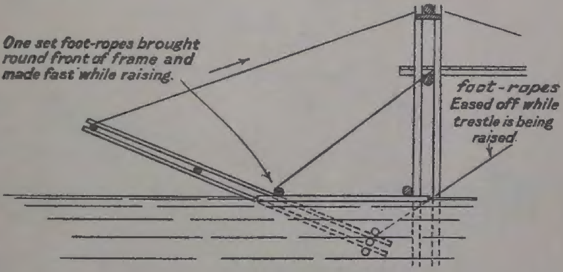
Elevation.

Fig. 2.



Trestle being raised.

Fig. 3.

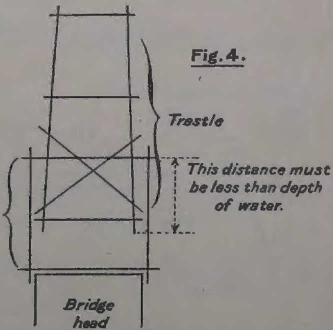


Plan.
(Line diagram.)

Trestle pushed under front of frame.

Frame.

Fig. 4.



LAUNCHING TRESTLES.

Fig. 1.

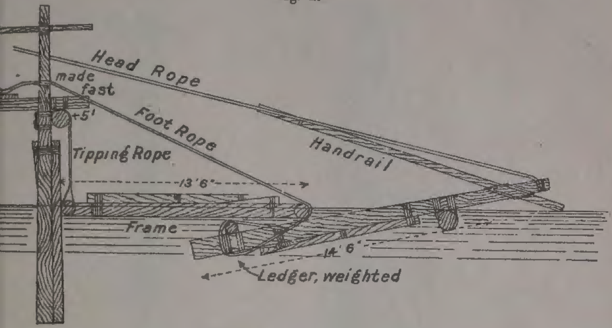


Fig. 2.

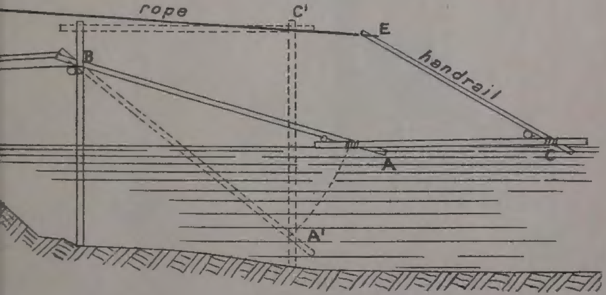
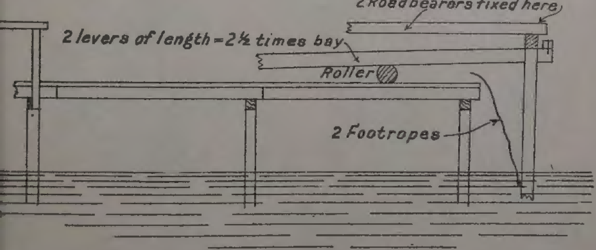


Fig. 3.



PILE DRIVING.

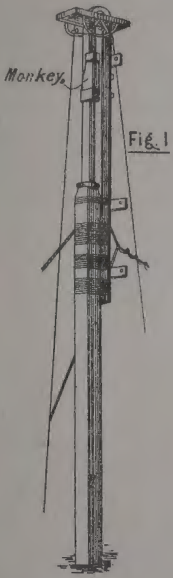


Fig. 1

Fig. 2.

Tripping Lever

Fig. 3

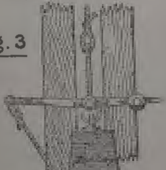
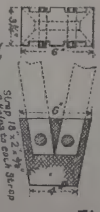


Fig. 4.

Chisel Pointed



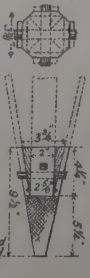


Fig. 5.

Diamond pointed

PILE DRIVING.

Fig. 1.

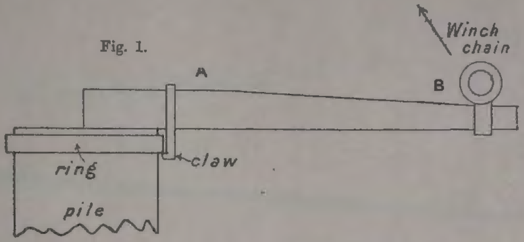


Fig. 2.

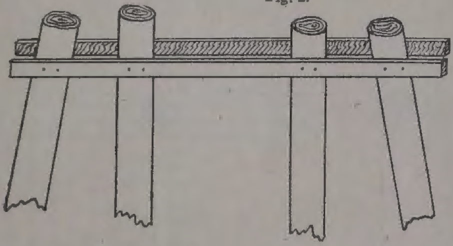


Fig. 3.

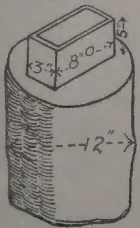


Fig. 4.

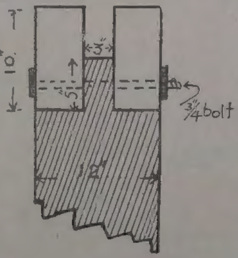
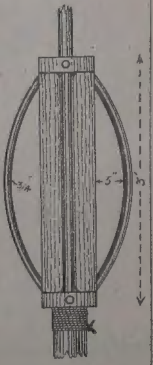


Fig. 5.



PILE DRIVING.

Driving Piles from Cantilevers.

Fig. 1.

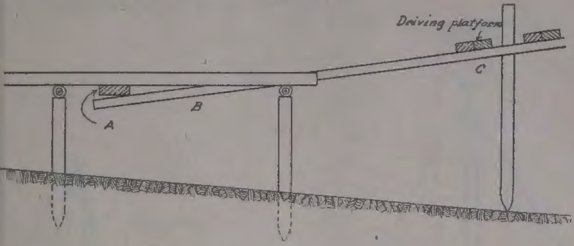
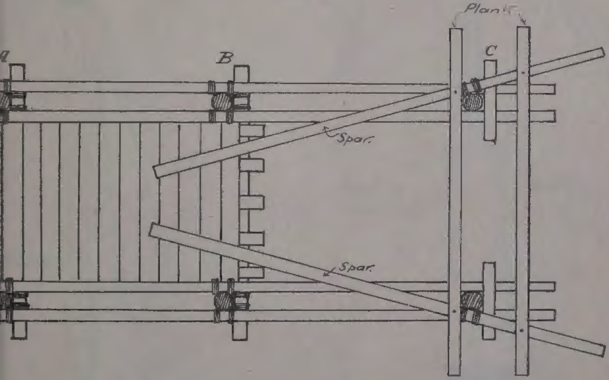


Fig. 2.



Rapid Light Pile Foot Bridge.

Fig. 3.

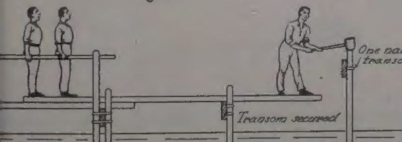
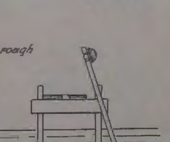
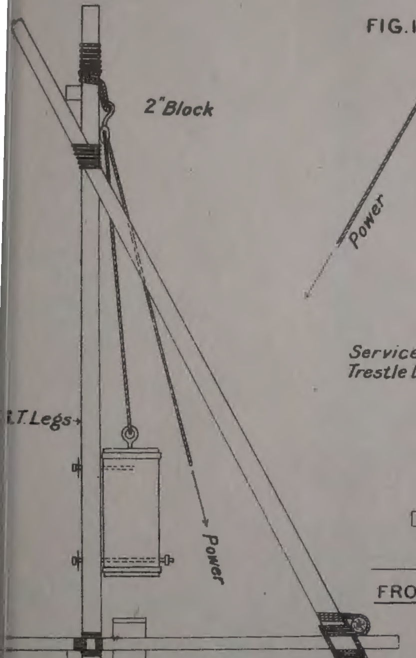


Fig. 4.



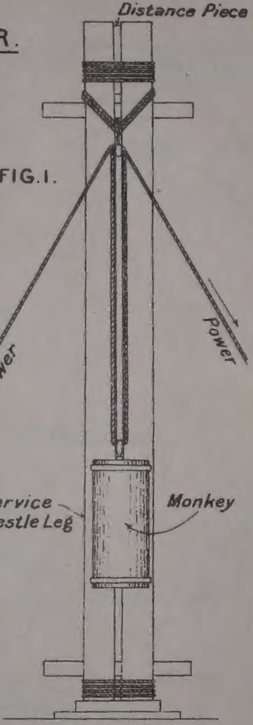
IMPROVISED PILE DRIVER.

FIG. 2.



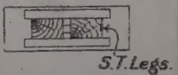
SIDE ELEVATION.

FIG. 1.



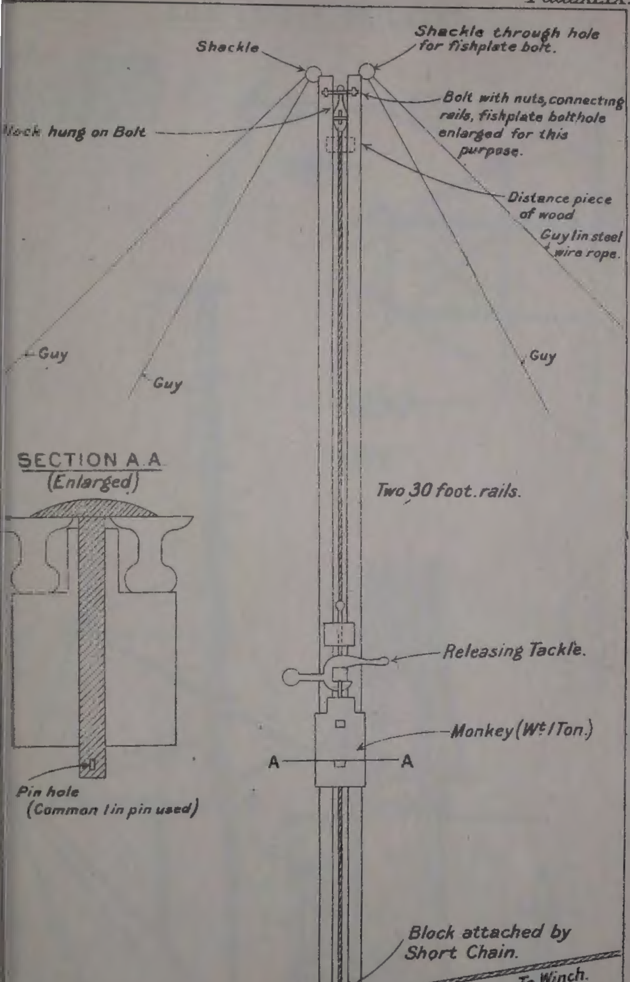
FRONT ELEVATION.

FIG. 3.



PLAN.

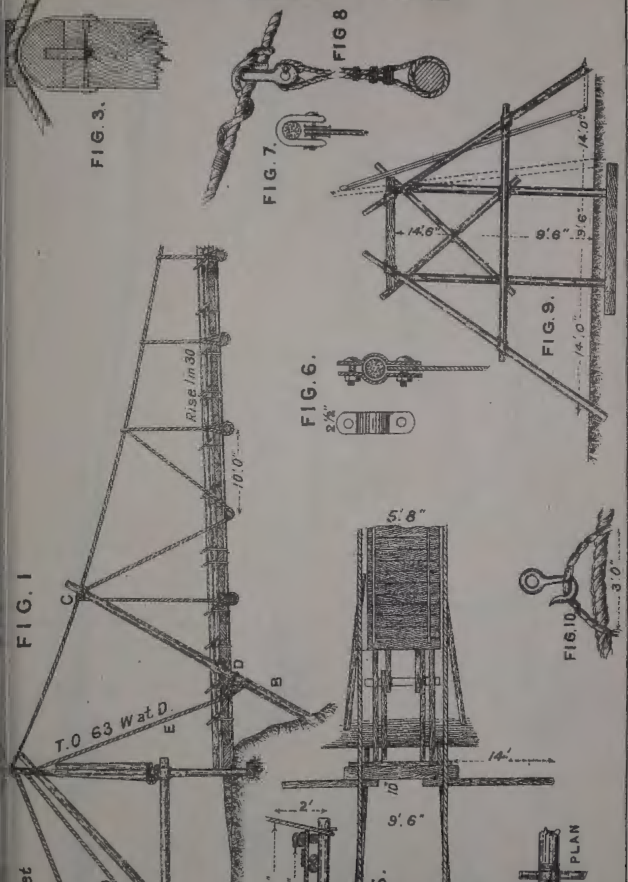
Malby & Sons, Lith.



Malby & Sons Lith.

Plate L

SUSPENSION BRIDGES.



Malby & Sons. Lith.

SUSPENSION BRIDGES.

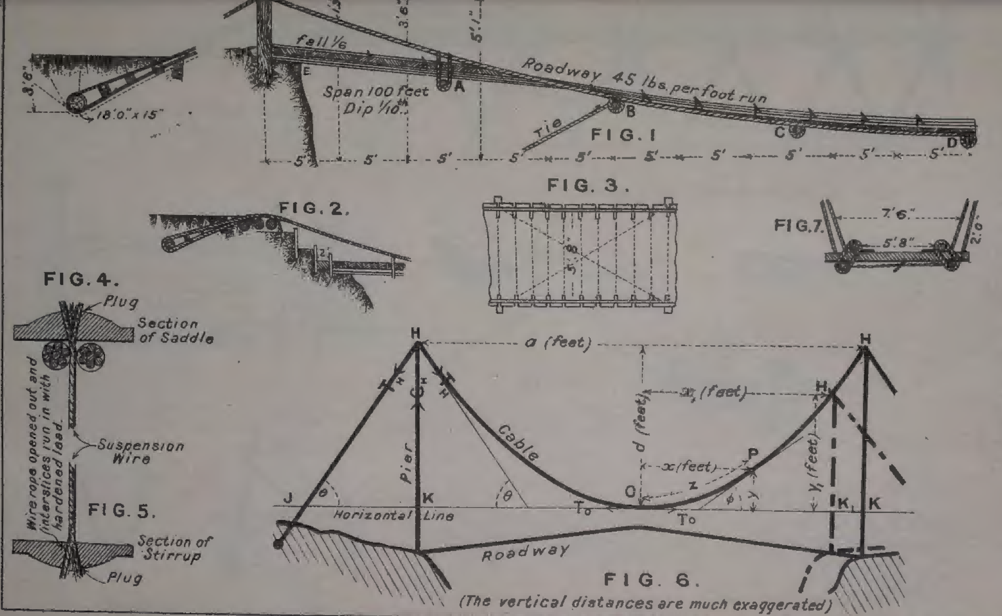


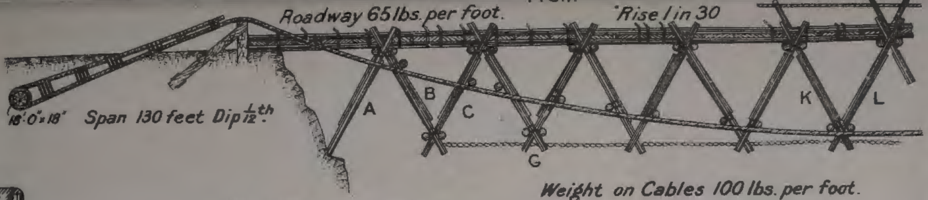
Plate LI

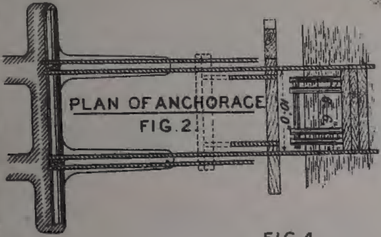
Malby & Sons. Lith.

SUSPENSION BRIDGES.

Plate LII.

FIG. 1.





PLAN OF ANCHORAGE
FIG. 2.

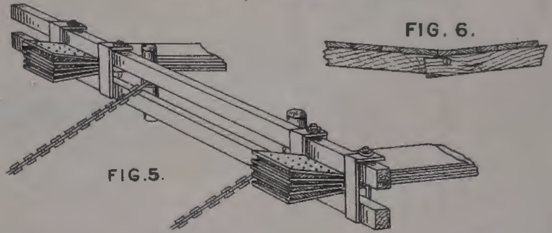


FIG. 5.

FIG. 6.

FIG. 3.

FIG. 4.

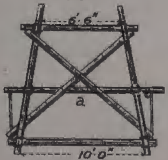


FIG. 7.

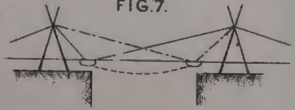
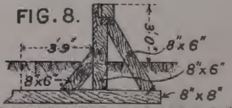


FIG. 8.



ELEVATION OF HALF PIER FIG. 1.

Melby & Sons, Lith.

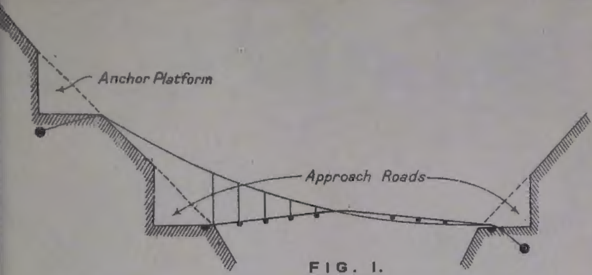


FIG. 1.

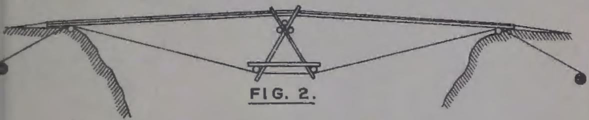


FIG. 2.

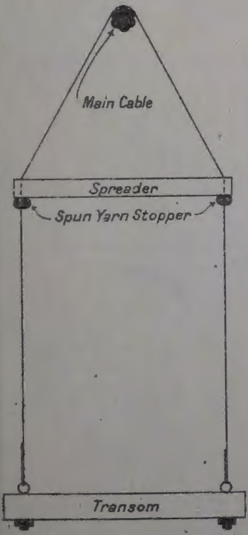


FIG. 3.

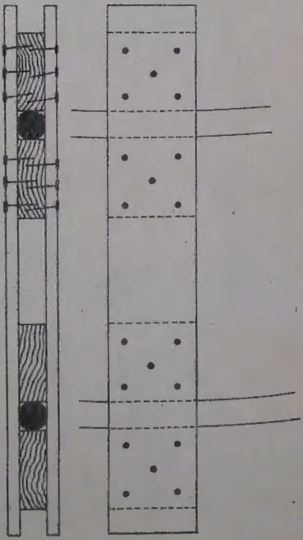


FIG. 4.

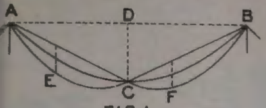


FIG. 1.

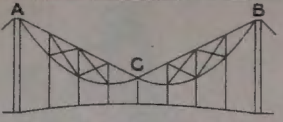


FIG. 2.

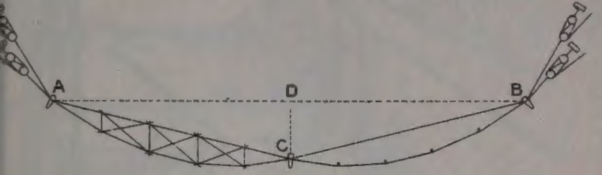


FIG. 3.

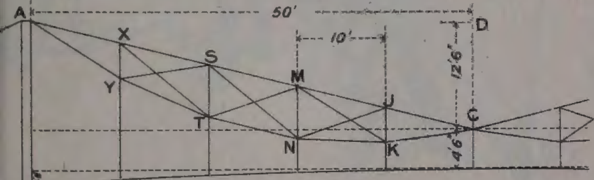


FIG. 4.

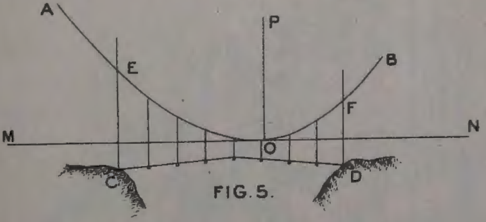


FIG. 5.

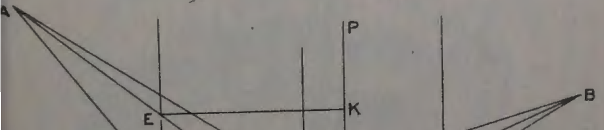


FIG 6.

Malby & Sons, Lith

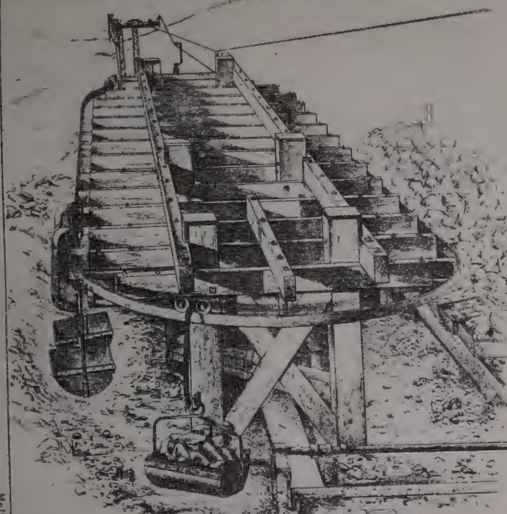


FIG. I.

SYSTEM I:– CARRIERS ON SHUNT RAIL,
SHOWING FRICTIONAL GRIP & SHUNT WHEELS.

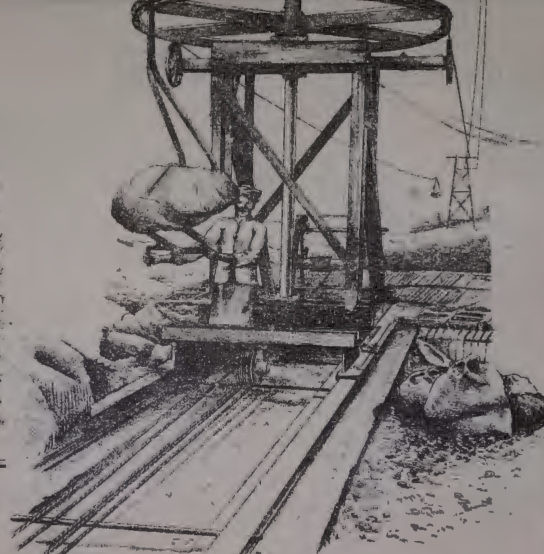


FIG. 2.

TIGHTENING GEAR FOR SYSTEM 2.

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Malby & Sons, Lith.

Plate LVI.

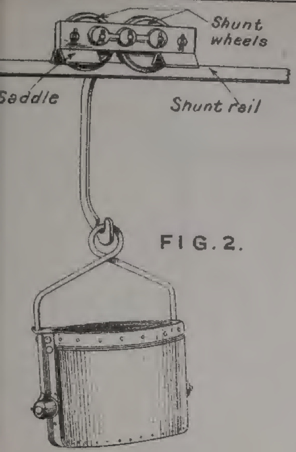

FIG. 2.

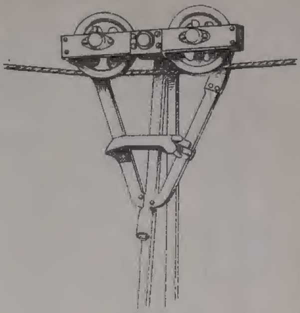

FIG. 1.

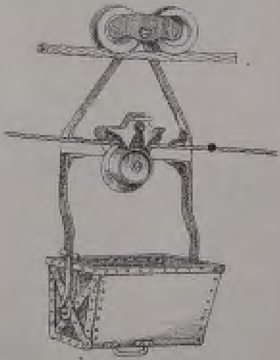

FIG. 3.

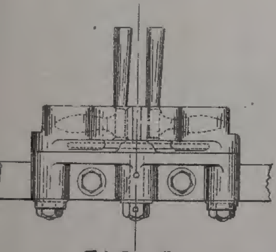

FIG. 5.

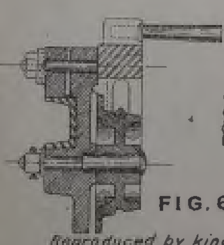

FIG. 6.

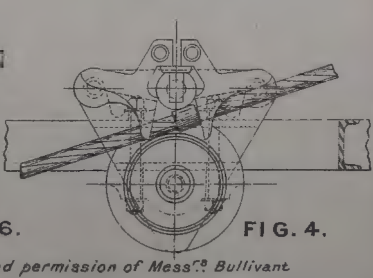

FIG. 4.

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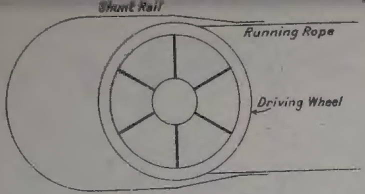

FIG. 1.

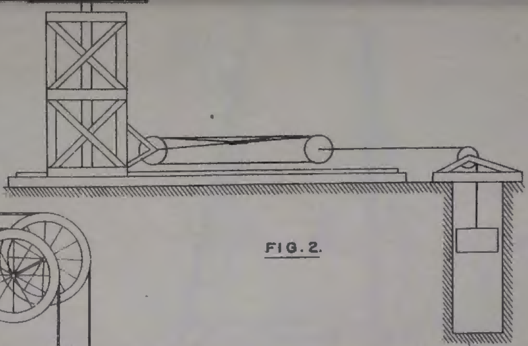

FIG. 2.

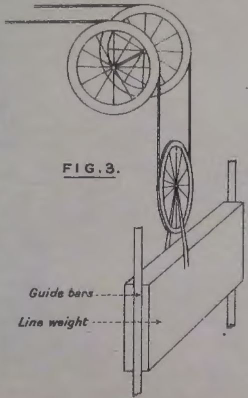

FIG. 3.

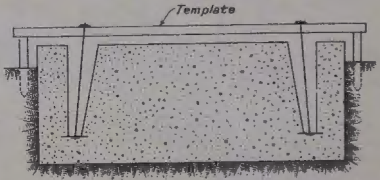

FIG. 4.

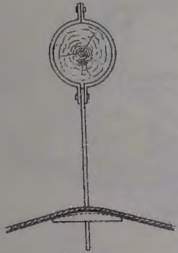

FIG. 5.

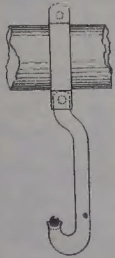

FIG. 6.

Malby & Sons, Lith.

Plate LVII.

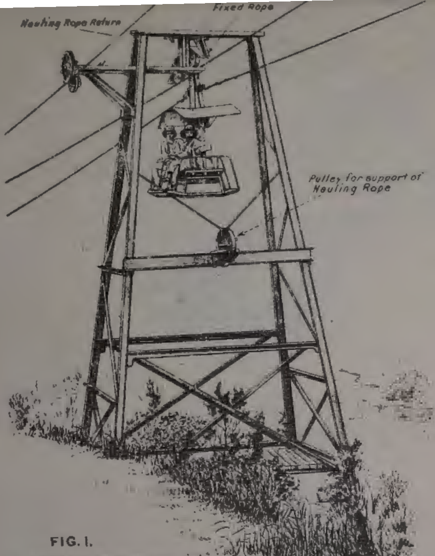

FIG. 1.

CARRIER PASSING STANDARD AND LIFTING GUIDE FOR CARRYING ROPE.

FIG. 2.

STANDARD FOR SYSTEM 4.
GUIDE FOR CARRYING ROPE IN NORMAL POSITION.

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Malby & Sons, Lith.

Plate LVIII.

Plate LIX.

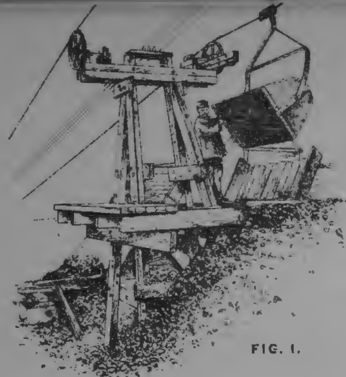


FIG. 1.

FIG. 3.

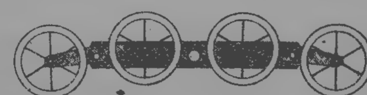


FIG. 4.

FIG. 2. *Reproduced by kind permission of Mess.rs Bullivant*

Malby & Sons, Lith.

Fig. 1.

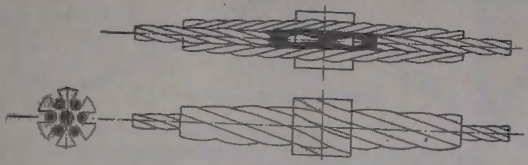


Fig. 2.

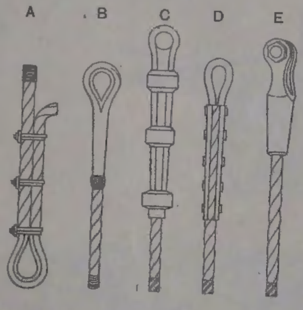


Fig. 3.

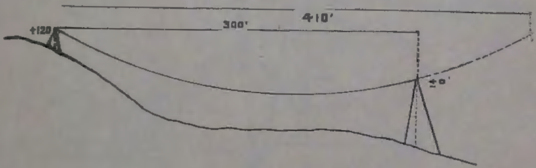
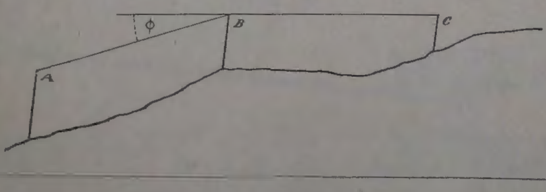
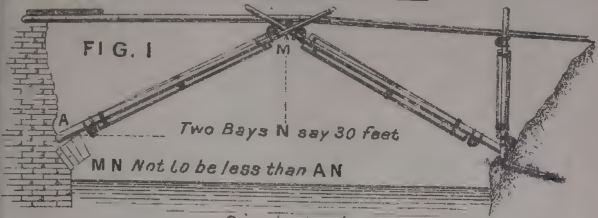


Fig. 4.



FRAME BRIDGES.

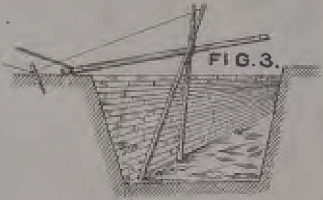
FIG. 1



Single Lock

FIG. 2.

FIG. 3.



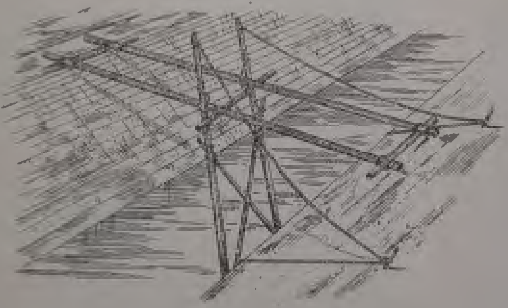


FIG. 4.

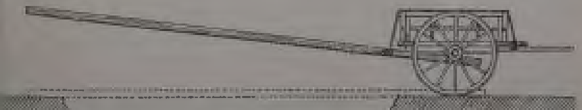
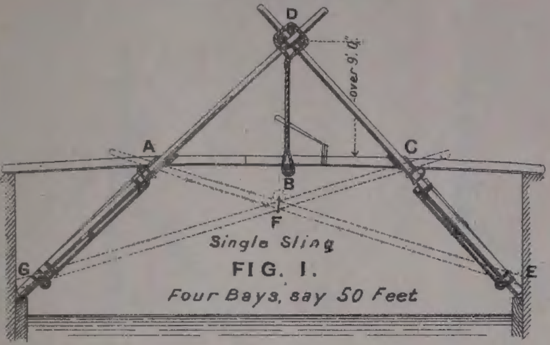


FIG. 5.

Malby & Sons Lith

SLING BRIDGES.



Single Sling

FIG. 1.

Four Bays, say 50 Feet

FIG. 2.

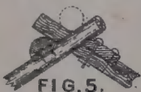


FIG. 5.

FIG. 3.

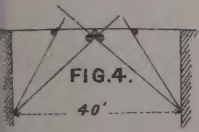


FIG. 4.

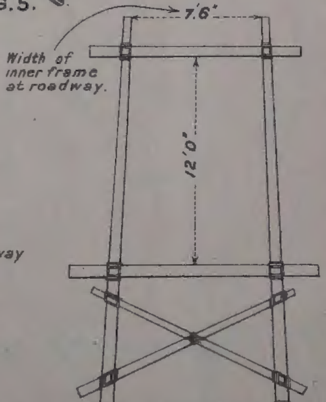


FIG. 7.

Long Frame.

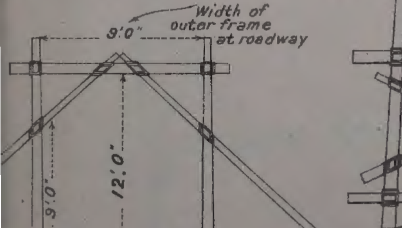


FIG. 6.

Short Frame

SLING BRIDGES

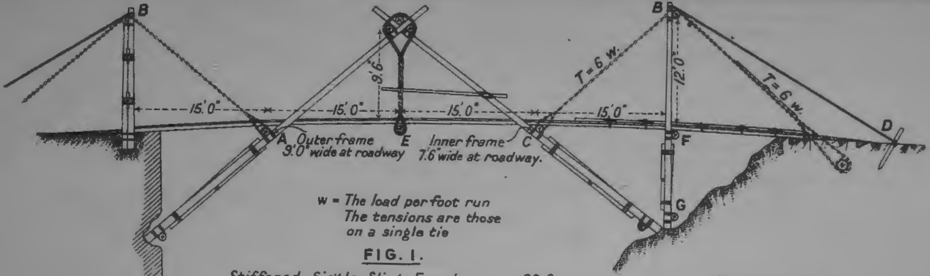


FIG. 1.

Stiffened Single Sling. Four bays, say 60 feet.

Handrails should be added to complete the bridges.

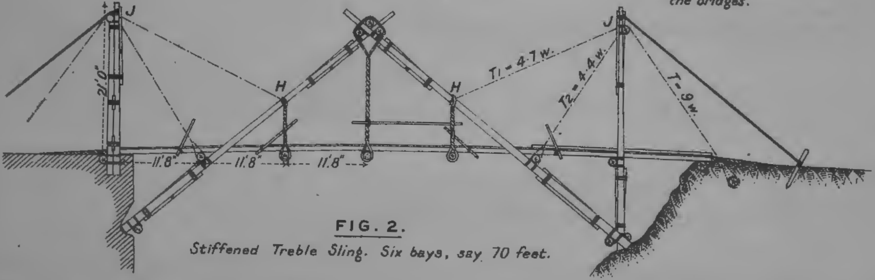


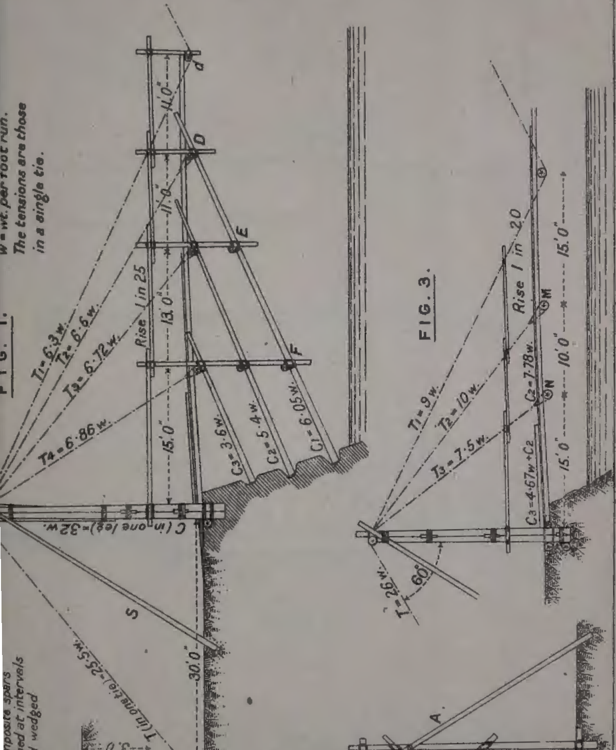
FIG. 2.

Stiffened Treble Sling. Six bays, say 70 feet.

Plate LXIII.

Mellby & Sons, Lith.

TENSION BRIDGES.



Malby & Sons, Lith.

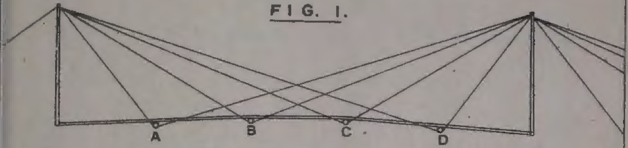


FIG. 1.

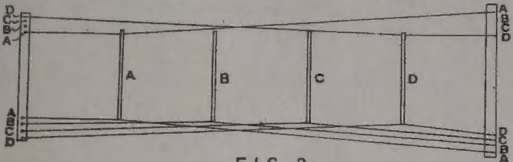


FIG. 2.

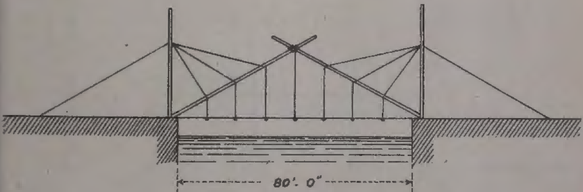


FIG. 3.

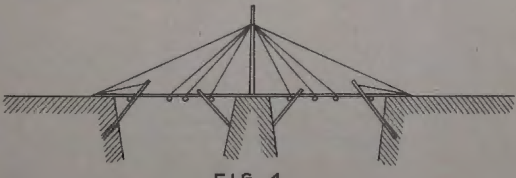


FIG. 4.

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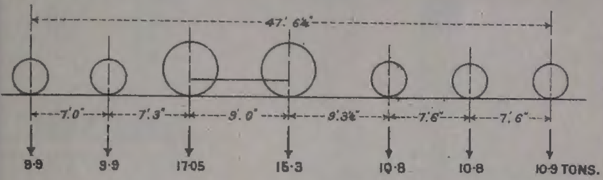
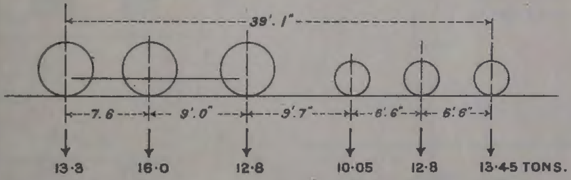
THE THREE LOCOMOTIVES REFERRED TO ARE :—

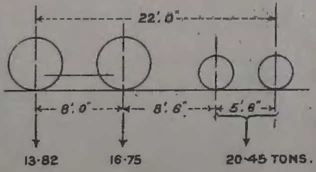
I. G.W.R. 4'. 8½" GAUGE. 4.4.0 (TENDER)



II. L.S.W.R. 4'. 8½" GAUGE 0.6.0 (TENDER)



III. M.R. 4'. 8½" GAUGE 0. 4. 4 (TANK)



Malby & Sons, Lith.

GROUPING AND FIXING OF RAIL BEARERS.

FIG. 1.

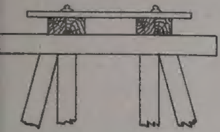


FIG. 2.

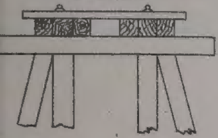


FIG. 3.

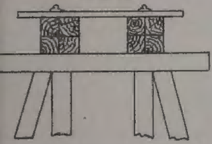


FIG. 4.

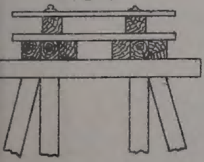


FIG. 5.

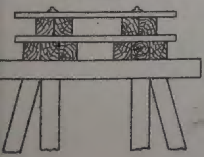


FIG. 6.

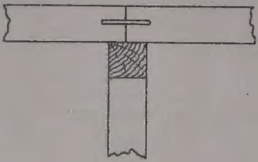


FIG. 7.

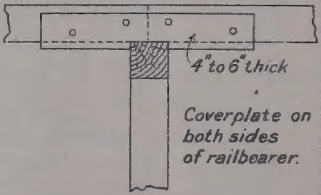


FIG. 8.

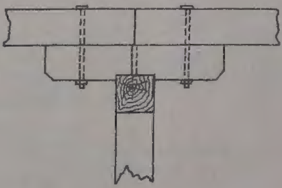
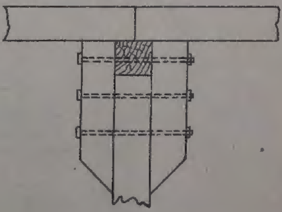


FIG. 9.



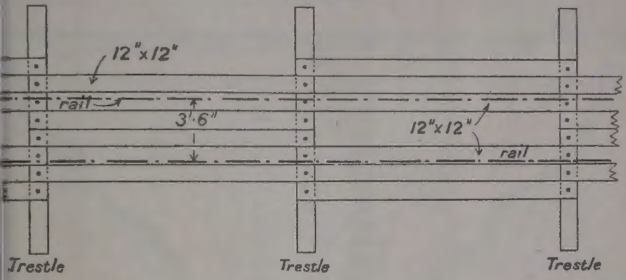
Malby & Sons, Lith.

TOP PLAN OF RAILBEARERS.

3′ 6″ gauge line.

Fig. 1.

3′6″ gauge line.

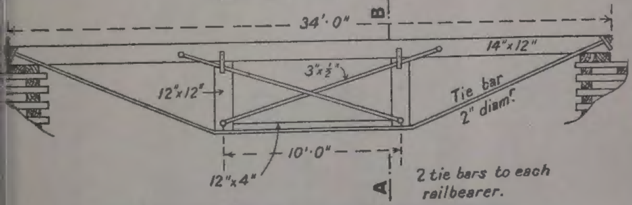


TRUSSED RAILBEARERS.

Side Elevation.

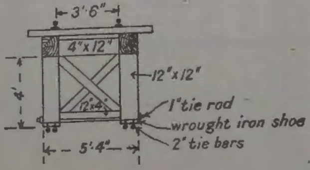
Fig. 2.

Side Elevation.



Section of Truss at A.B.

Fig. 3.



CRIB PIER.

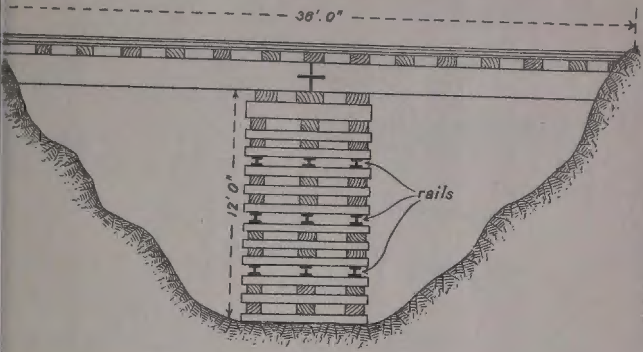


Fig. 1.

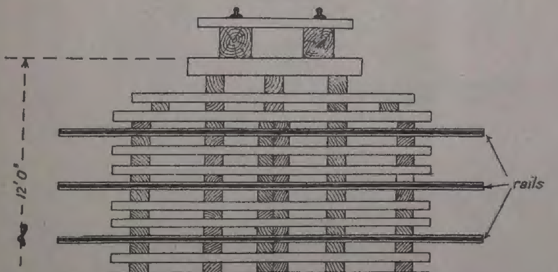


Fig. 2.

SINGLE-TIER TRESTLE.

12" × 12" Timber.

Fig. 1.

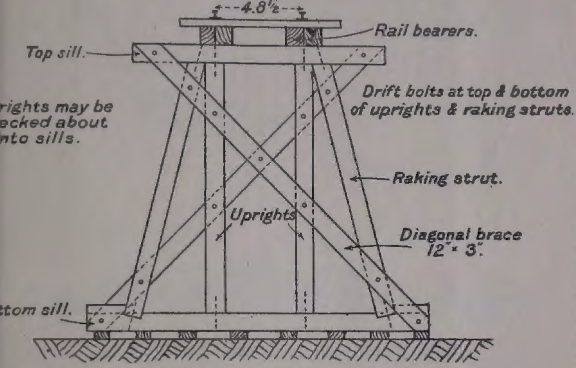
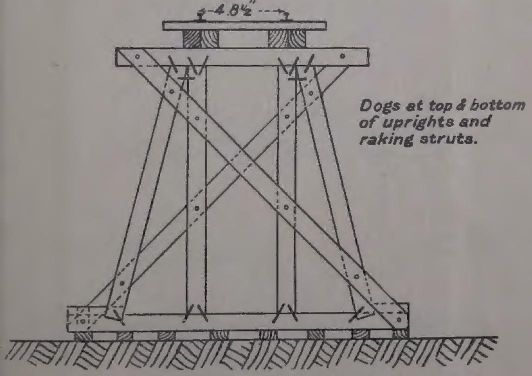
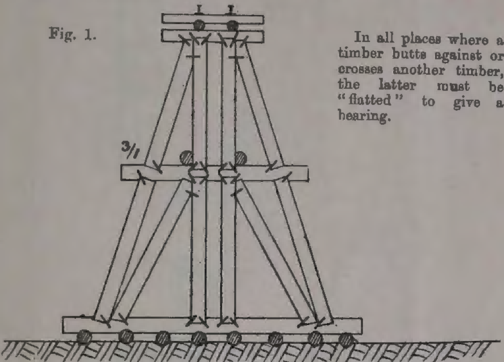


Fig. 2.



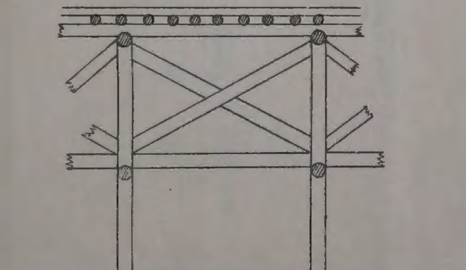
ROUND TIMBER TRESTLE.
LIGHT RAILWAY.

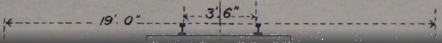
Fig. 1.



In all places where a timber butts against or crosses another timber, the latter must be "flatted" to give a bearing.

Fig. 2.





Note:-

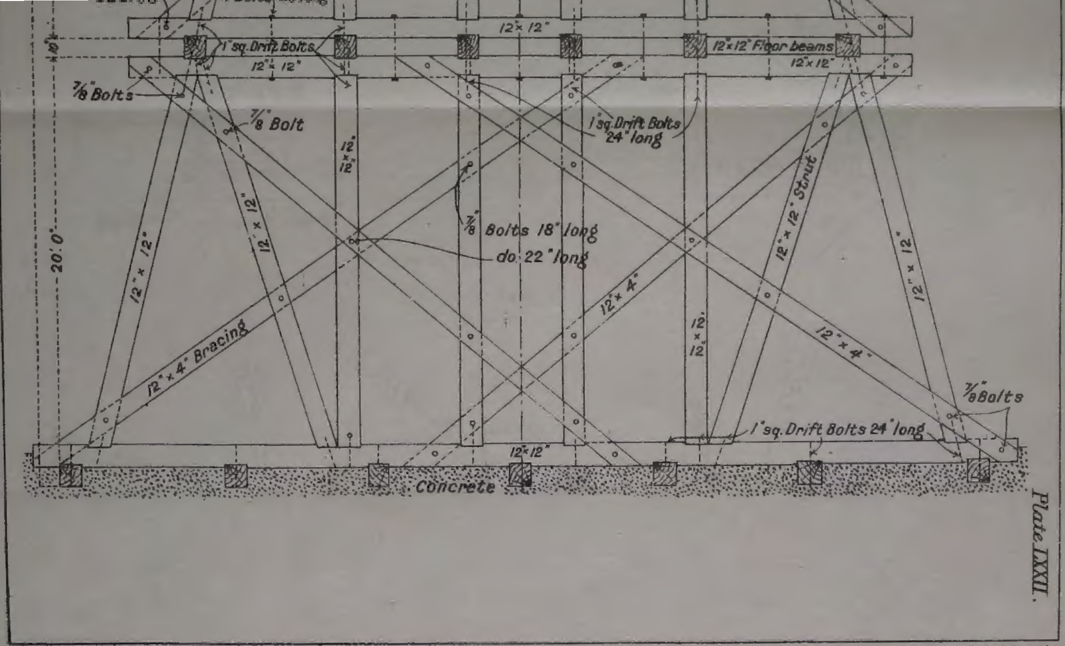


Plate LXXII.

2881.

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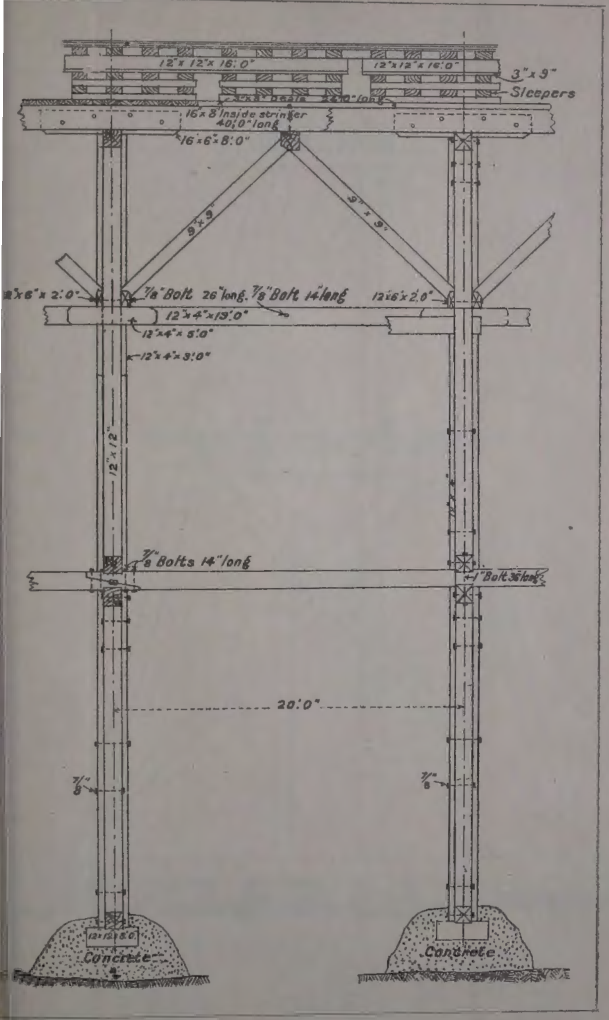
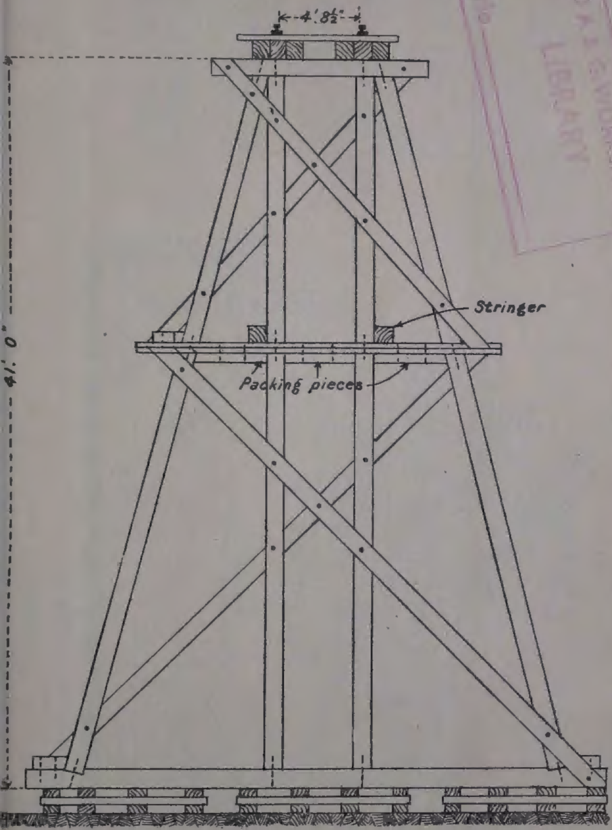
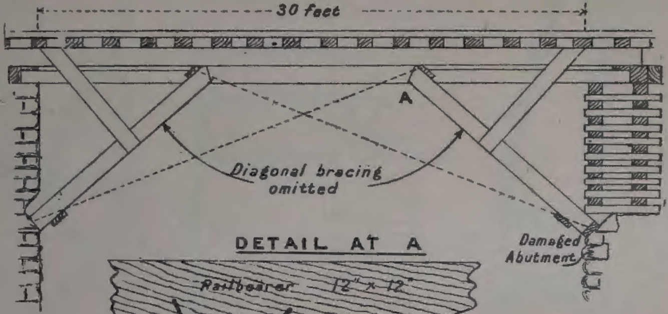

12"x 12"x 16:0"
12"x 12"x 16:0"
3"x 9"
Sleepers
16x 8 Inside stringer
40:0" long
16x6x8:0"
9"x 9"
9"x 9"
12"x 6"x 2:0"
7/8" Bolt 26" long. 7/8" Bolt 14" long
12"x6"x 2:0"
12"x 4"x 13:0"
12"x 4"x 5:0"
12"x 4"x 3:0"
12"x 12"
7/8" Bolts 14" long
1" Bolt 36" long
20:0"
7/8"
7/8"
12x12x 8:0
Concrete
Concrete

Two Tier Trestle.

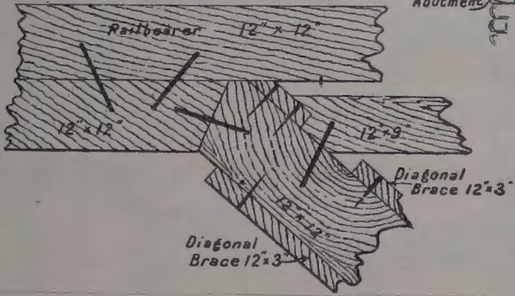


STRUTTED RAILWAY BRIDGE.

SIDE ELEVATION.



DETAIL AT A



UPPER SIDE OF INCLINED FRAME.

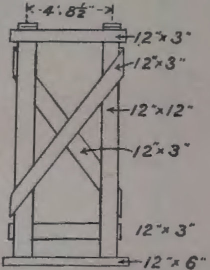


Plate LXXV.

REPAIRS TO BRIDGES.

Fig. 1.

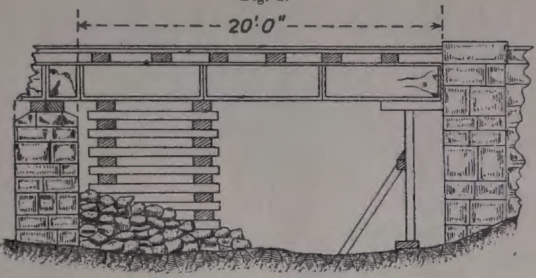


Fig. 2.

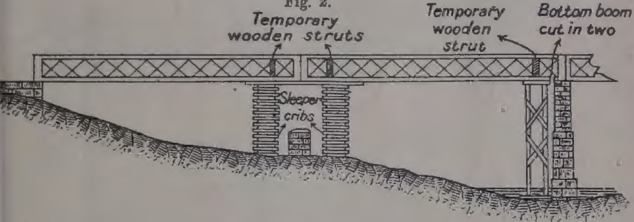


Fig. 3.

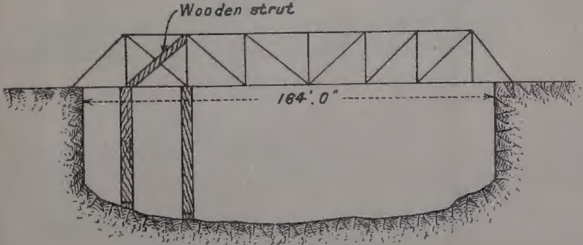
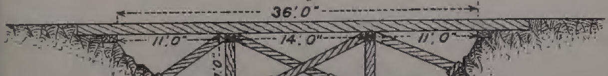
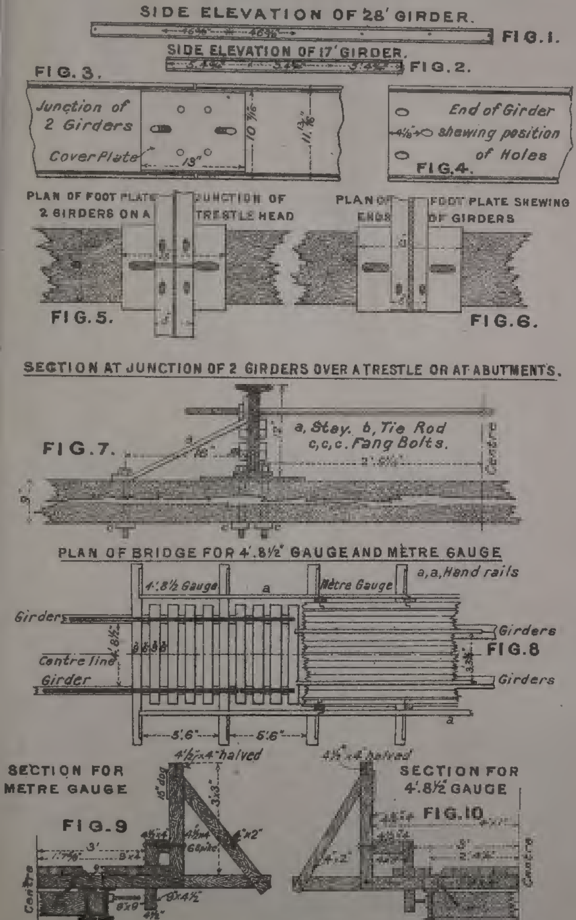


Fig. 4.



MASONRY ARCH BLOWN IN.

GIRDERS FOR TRAMWAY BRIDGES.



BOAT BRIDGE.

FIG. 1.

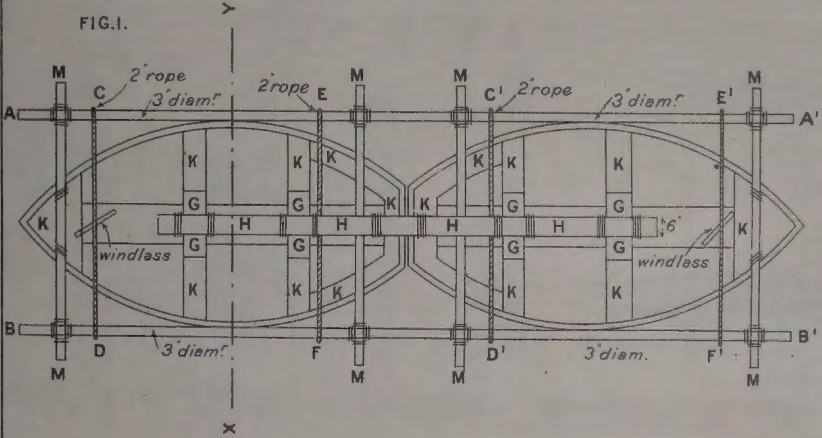
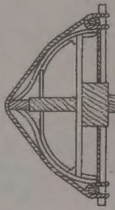


FIG. 2.

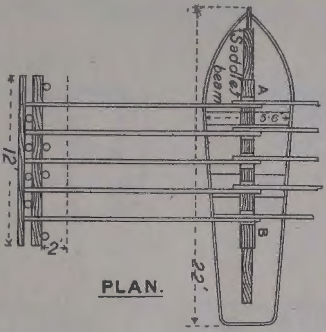


Malby & Sons. Lith.

Plate LXXVIII.

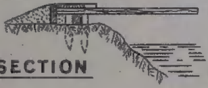
BOAT BRIDGE.

FIG. 1.



PLAN.

FIG. 2



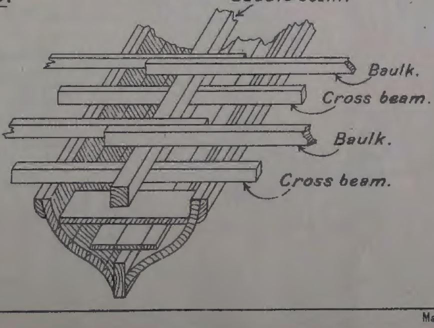
SECTION

FIG. 3.

FIG. 4.

SECTION ON A.B.

FIG. 5.



Malby & Sons, Lith.

BARREL PIERS.

Method of lashing Barrels to Gunnels.

Fig. 1.

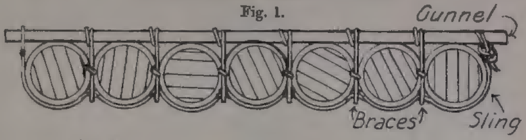


Fig. 2.

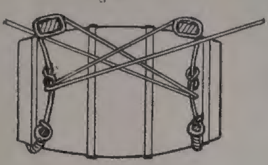


Fig. 3.

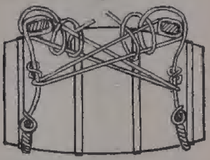


Fig. 4.

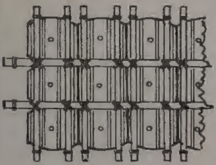


Fig. 5.

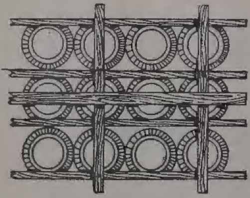
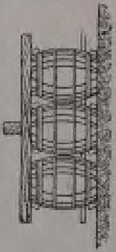


Fig. 5A.



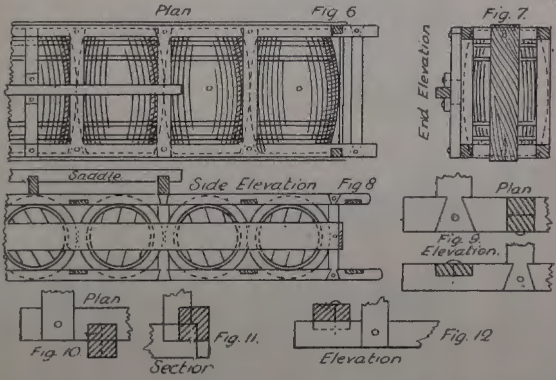
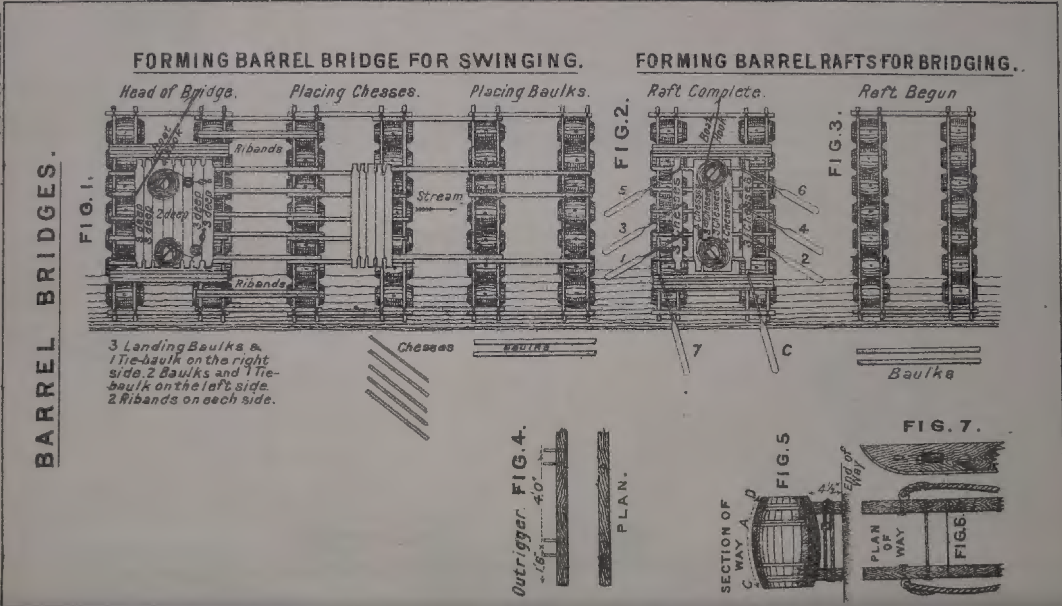


Plate LXXXI



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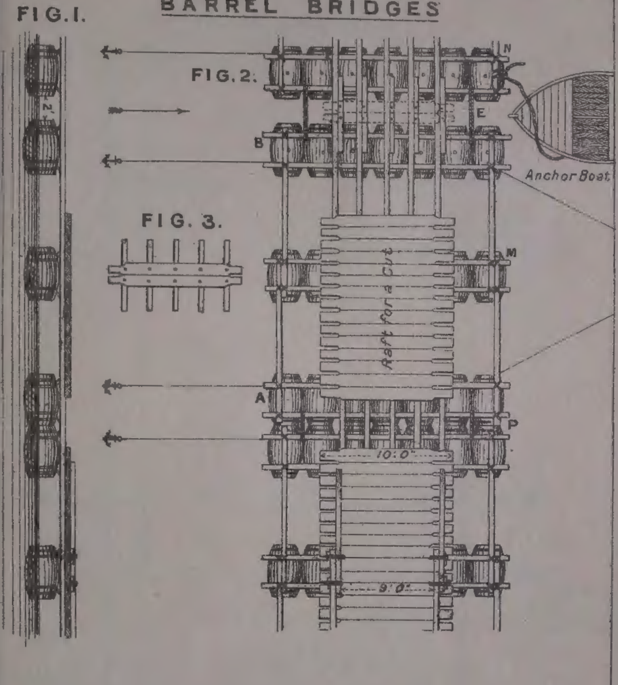
BARREL BRIDGES



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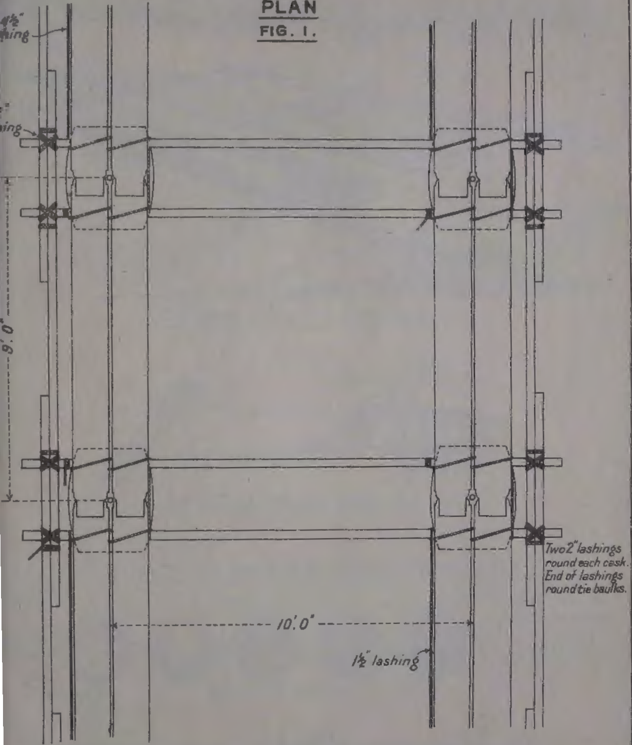
CASK FOOTBRIDGE.

For 54 gallon casks.

PLAN

FIG. 1.



Where time presses or materials are lacking, planks, one side only will suffice for infantry in file.

ELEVATION

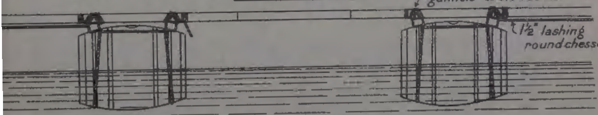
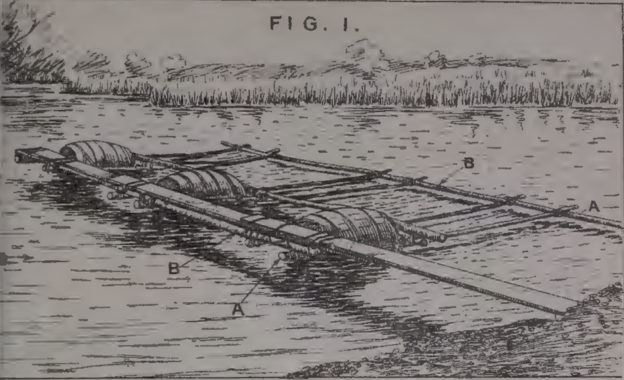


FIG. 2.

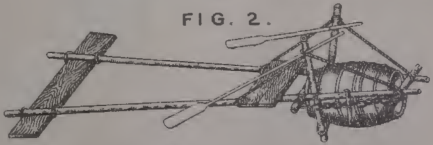
Malby & Sons, Lith.

FIG. 1.



CATAMARAN BRIDGE.

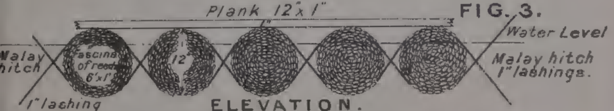
FIG. 2.



SINGLE BARREL RAFT.

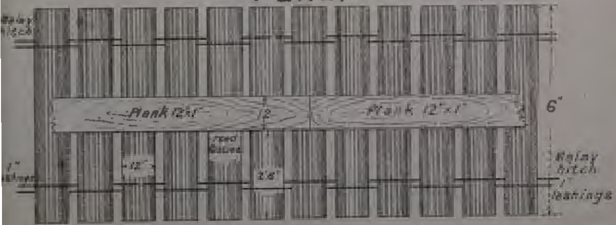
ROAD FASCINE FOOTBRIDGE.

FIG. 3.



ELEVATION.

PLAN. FIG. 4.



921.

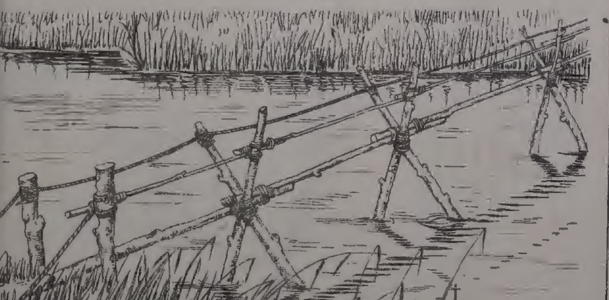
Malby & Sons, Lith

Plate LXXXV.

FIG. 1.

BAMBOO OR LIGHT BRUSHWOOD BRIDGE.

FIG. 2.



HOP-POLE BRIDGE.

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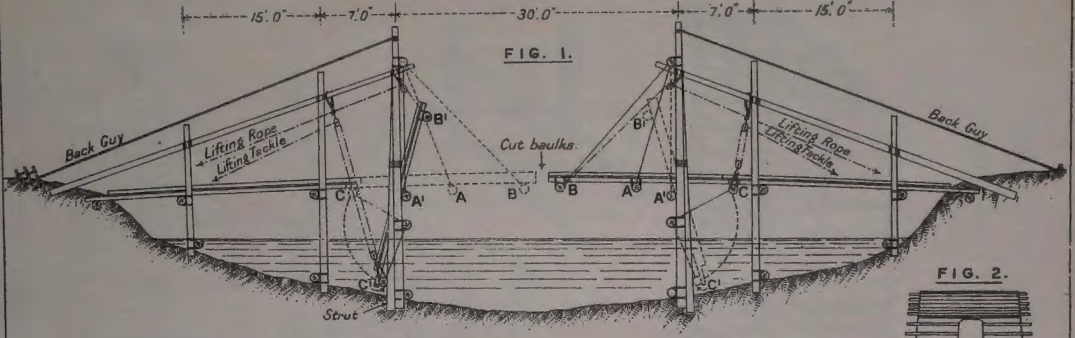
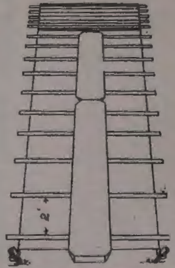
IMPROVISED DRAWBRIDGE

FIG. 1.



Strains calculated graphically for Infantry in fours.
Slings and guys of ¾" steel wire rope.
The lifting can be done by four men on each side.
The shore ends of drawbridge fit when the centre is pulled together by the closing tackles, and cut baulks are provided for the centre.
Wood chocks are provided to drop between drawbridge and frame to prevent side swaying.

FIG. 2.



CANVAS TRACK OVER MARSH.

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Plate LXXXVI.

SHEET BOATS.

GENERAL VIEW OF FRAMEWORK.

FIG. I.

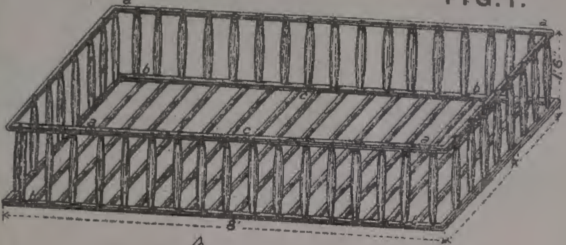


FIG. 2.

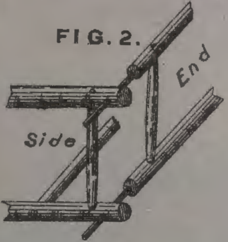
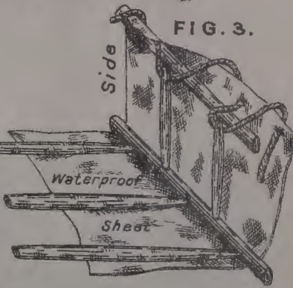


FIG. 3.



SIDE OF BRIDGE.

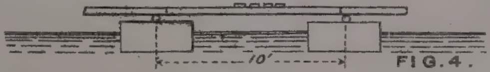


FIG. 4.

PLAN.

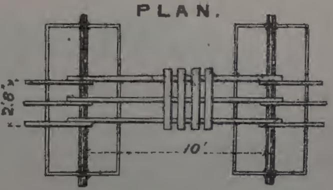
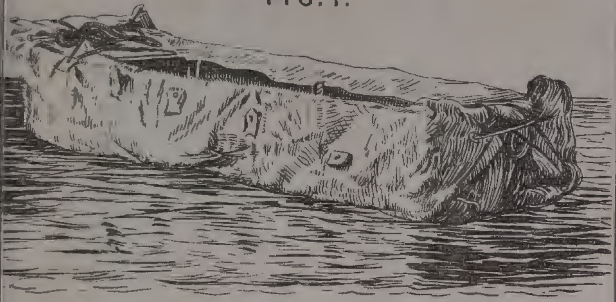


FIG. 5.

FIG. I.



BOAT OF G. S. WAGON & COVER.

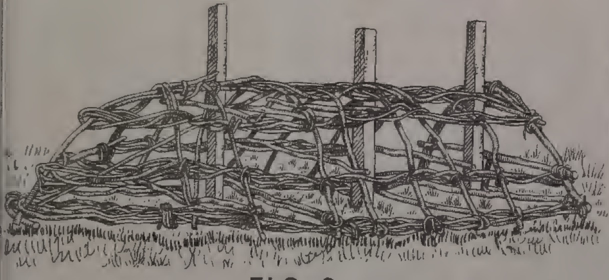


FIG. 2.

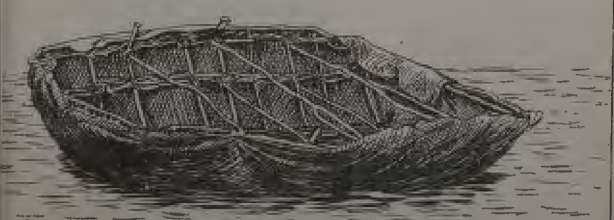


FIG. 3.

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FIG. 1

FIG. 2.

RAFT OF TARPAULIN & STRAW.

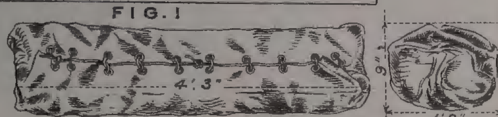
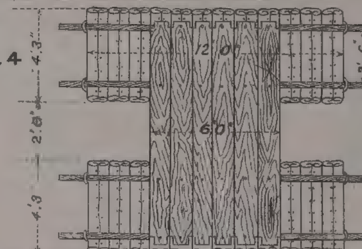


FIG 3.

FIG. 4



Raft of 24 ground-sheets as Fig. 3

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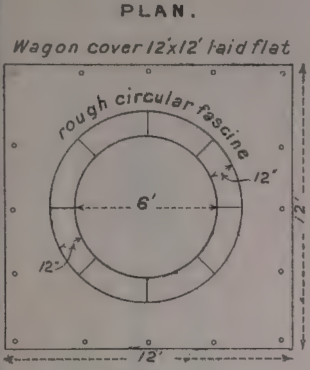

FIG. 1.

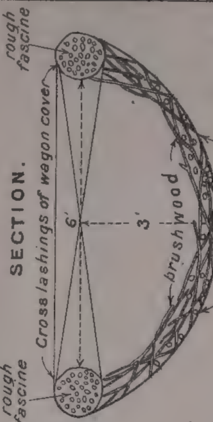

FIG. 2.

BIRDS NEST BOAT.

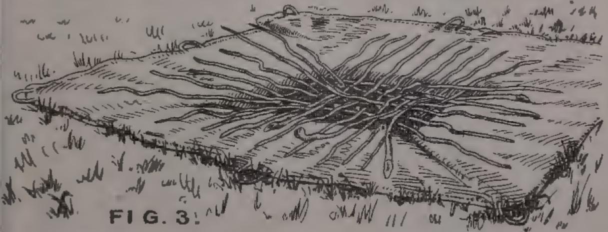

FIG. 3.

FIG. 4.

Plate XCI.

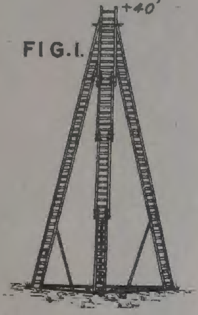

FIG.1.

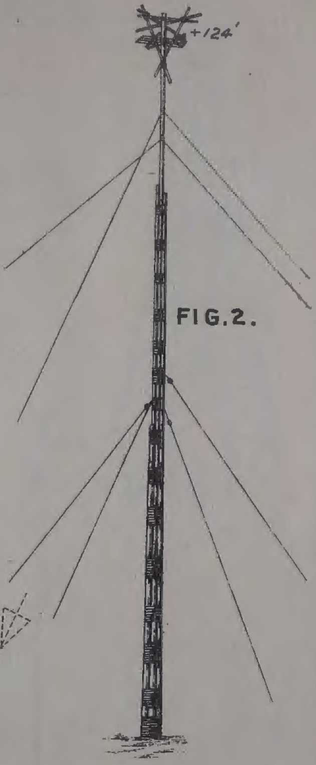

FIG.2.

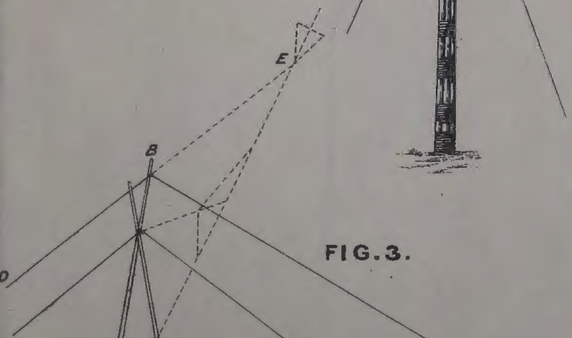

FIG.3.

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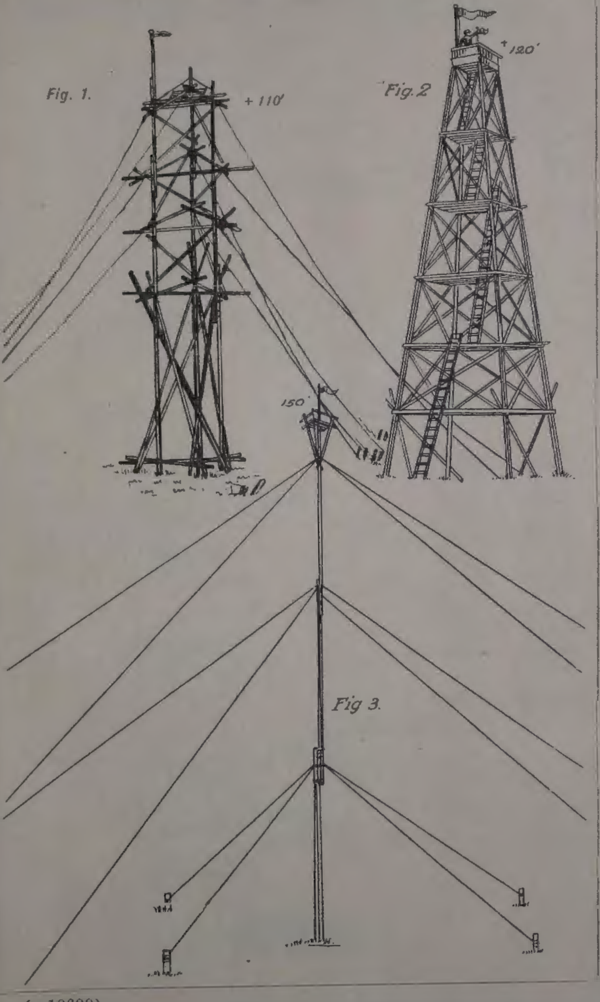
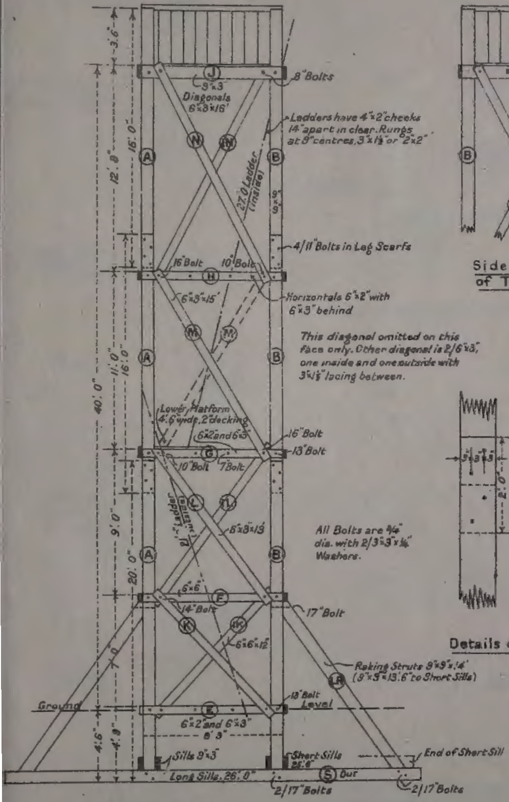
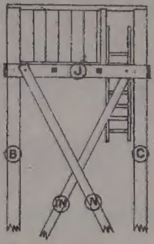
OBSERVATORIES.



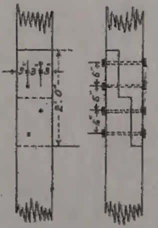
OBSERVATORY FOR ARTILLERY RANGE.



Elevation.



Side Elevation of Top Panel.



Details of Leg Scarfs

Letters in circles refer to marking for Re-erection.

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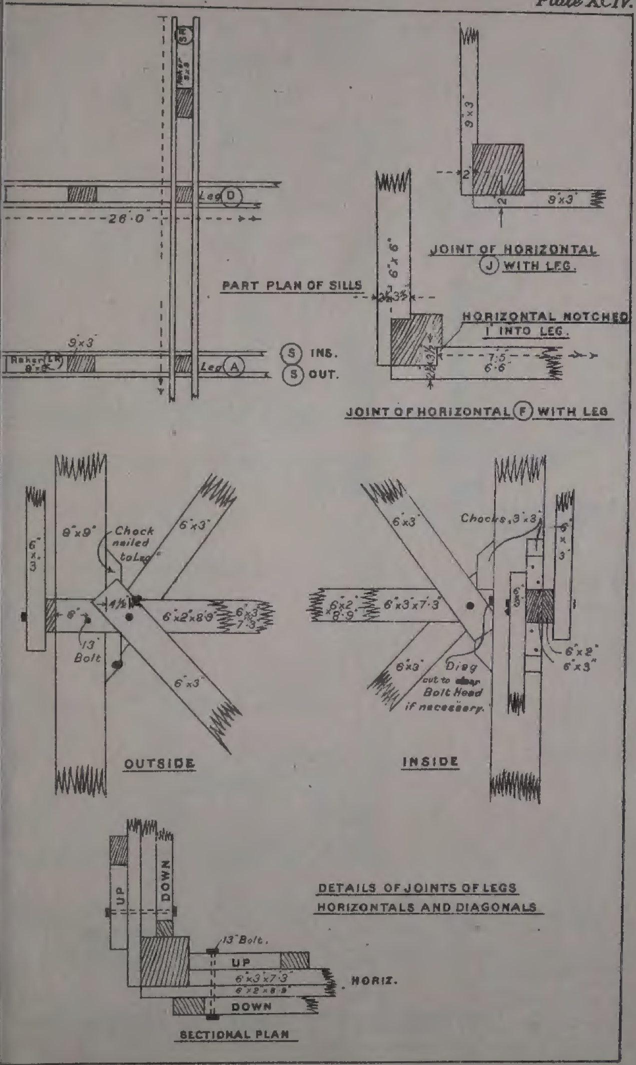

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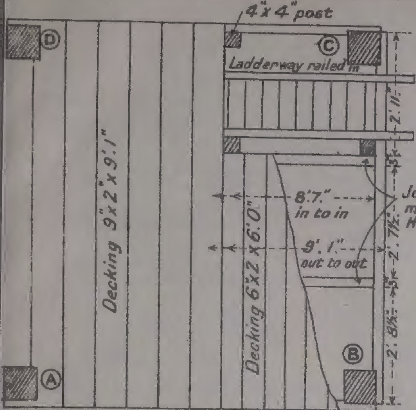
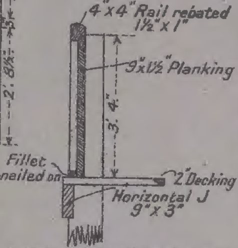
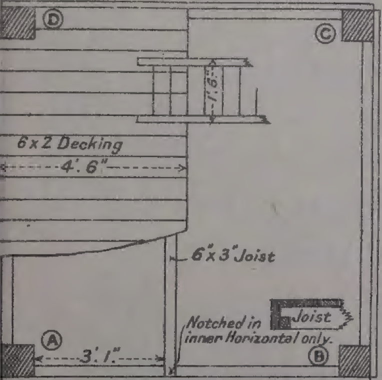


ARRANGEMENT OF TOP PLATFORM

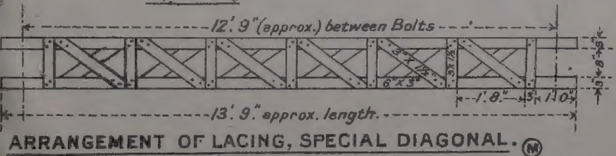


ARRANGEMENT OF RAILING TO TOP PLATFORM.



ARRANGEMENT OF LOWER PLATFORM

½" = 1 foot



ARRANGEMENT OF LACING, SPECIAL DIAGONAL. (M)

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The Hampshire Regiment.
The Highland Light Infantry.
The King's Own Yorkshire Light Infantry.
The Lancashire Fusiliers.
The Northamptonshire Regiment.
The Oxfordshire and Buckinghamshire Light Infantry.
The Prince Albert's (Somersetshire Light Infantry).
The Prince of Wales's Leinster Regiment (Royal Canadians).
The Princess Charlotte of Wales's (The Royal Berkshire Regiment).
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