WAR DEPARTMENT

ENGINEER FIELD MANUAL

Volume II
MILITARY ENGINEERING
(*TENTATIVE*)

PART ONE
COMMUNICATIONS

ENGINEER FIELD MANUAL

VOLUME II

MILITARY ENGINEERING

(*TENTATIVE*)

PART ONE

COMMUNICATIONS

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CHIEF OF ENGINEERS

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Part One, Communications, Engineer Field Manual, Volume II, Military Engineering (Tentative), is published for the information and guidance of all concerned.

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BY ORDER OF THE SECRETARY OF WAR:

DOUGLAS MACARTHUR,
General,
Chief of Staff.

OFFICIAL:
C. H. BRIDGES,
Major General,
The Adjutant General.

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Signal Corps Field Manual. (S. C. F. M.)

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FOREWORD

Engineer Field Manual, Volume II, Military Engineering, is a compendium of technical information and suggestions as to the conduct of the most common operations undertaken by engineer troops in the theater of operations. The user of this manual should recognize that local conditions in the field will always profoundly affect the application of the principles and formulas given herein. The manual contains suggestions and guides to judgment rather than regulations to be rigidly adhered to.

The manual will be published in three parts as follows:

Part One. Communications:
- Chapter 1. Roads.
- 2. Bridges.
- 3. Military railways.
- 4. Surveys and maps. (This chapter will be published when it becomes necessary to revise TM 2180–30 and 2180–37.).

Part Two. Defensive measures:
- Chapter 1. Camouflage.
- 2. Field fortifications.
- 3. Explosives and demolitions.

Part Three. Construction and utilities:
- Chapter 1. General construction.
- 2. Water supply.
- 3. Light and power.

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VOLUME II, MILITARY ENGINEERING

(TENTATIVE)

Part One

Communications

(The matter contained herein supersedes TR 445–170, June 29, 1929 (including C1, January 2, 1931); 445–205, July 13, 1923; 445–210, January 24, 1925; 445–220, July 13, 1923 (including C1, January 2, 1931); 445–230, November 26, 1924; and 445–235, July 13, 1923; Military Railways, Edition of 1917 (Professional Papers No. 32, Corps of Engineers, U. S. Army), and the Ponton Manual, 1917. Volume II supersedes the Engineer Field Manual, Edition of 1918 (Professional Papers of the Corps of Engineers, U. S. Army, No. 29).)

CHAPTER 1

ROADS

SECTION I

GENERAL PRINCIPLES

1. General.—Economy of time, material, transportation, and labor requires the maximum utilization of the existing road net. New road construction is held to the minimum by the repair and maintenance of existing roads, meeting increased demands by increasing the capacity of existing roads rather than by undertaking new construction. Under the heavy and continuous traffic of operations, maintenance alone entails a large supply of materials with much plant and a considerable force. Experience has shown, however, that certain new road construction is necessary in connection with base establishments, and in major operations new roads of emergency construction are often required to facilitate supply and the movement of artillery.

2. Traffic demands.—Road traffic is at a maximum during offensive operations when, in addition to food, forage, and oil, demands for ammunition and engineer materials are at their highest. The exploitation of a tactical success requires that the advance of troops be not halted on account of lack of supplies. The roads in the forward areas must therefore be made passable as soon as practicable for animal-drawn vehicles, field and combat trains, and field artillery.

3. Road capacity.—By the capacity of a road is meant the maximum practicable transport tonnage which can be moved over it in a given period of time. This is dependent upon the width, structural character, and condition of the road and upon the regulation of the traffic. The capacity of a road may be limited by the capacity of its bridges. These may fix the character of traffic loads which may be permitted to use the road, and, if narrow and at fairly short intervals along the road, may limit the number of lanes of traffic which the road might otherwise be suitable to carry. The amount of transportation which can use a given road in a given period of time depends upon the speed at which the vehicles are permitted to travel and the interval between the vehicles. Experience indicates that the amount of transportation is not increased by excessive speeds, since these imply a corresponding increase of interval between vehicles for safety. Excessive speeds increase maintenance requirements, and hence the capacity of a road is also limited by the question of maintenance.

4. Tactical requirements.—At least one road for two columns of traffic or its equivalent is necessary for each infantry division in line. This distribution would normally give the division 1 road, the corps 2 roads, and the army 6. The distance at which troops can be supplied by a road varies with the road condition. In the World War this was found to vary from 60 to 75 miles from the railhead.

5. Traffic regulation on roads.—In order that the roads may give the maximum of service, it is necessary to regulate traffic both as to direction and speed and to separate slowly moving columns from rapidly moving columns. High speed causes great destructive effect upon the roads, expecially on curves and on the edges. The principal destructive effect is produced by the driving wheels, which produce a shearing force between the wheel and the road. This force increases with the speed and weight of the vehicles. In the preparation of traffic-control regulations the engineers should be consulted as to the classes of vehicles allo on various roads, their speeds and direction of movement.

6. Nomenclature.—*a. Foundation.*—The portion of the roadway below and supporting the crust.

b. Subgrade.—The upper surface of the native foundation on which is placed the road metal or the artificial foundation, in case the latter is provided.

c. Crust.—That portion of a macadam or similar roadway above the foundation consisting of the road metal proper with its bonding agent or binder.

d. Artificial foundation (base).—That layer of the foundation especially placed on the subgrade for the purpose of reinforcing the supporting power of the latter itself and composed of material different from that of the subgrade proper.

e. Ditch.—The open side drain of a road, usually deep in proportion to its width and unpaved.

f. Shoulder.—The portion of the road between the edge of the metal and the ditch, gutter, slope, or watercourse.

g. Wearing course.—The course of the crust exposed to traffic.

h. Crown.—The rise in cross section from the lowest to the highest part of the finished road.

i. Grade.—The profile of the center of the road, or its rate of rise or fall; slope.

j. Road metal.—Broken stone, gravel, slag, or similar material used in road construction or maintenance.

k. Axial road.—A road generally perpendicular to the front, and designated as main traffic artery of a division or higher unit. It should be capable of supporting motor traffic throughout and may be restricted to that class alone.

l. Lateral road.—A road generally parallel to the front; also called belt road.

m. Reserved road.—A road reserved for one class of traffic only; for example, for motor traffic.

7. Types.—*a. Trails.*—A trail is a narrow path or route suitable for foot traffic, pack animals, and machine-gun carts. The pathway has a minimum standard width of four feet, but in cutting trails through thick growth consideration must be given to the required clearance of the traffic in order that overhanging growth may not interfere.

b. Tread roads.—A tread road is one in which the bearing surface is prepared for the wheel treads only. This is the simplest and most quickly constructed hard-surfaced road. The treadways may be of any available material, including rock, plank or round timbers.

c. Wire-mesh roads.—In sandy, desert regions wire-mesh roads may be constructed, the number of layers of netting depending upon the amount and character of traffic to be sustained.

d. Corduroy road.—The corduroy road is one constructed by laying longitudinal sleepers of round or split logs across which a surface of small poles (4 to 6 inch diameter) is spiked. Such a road is used in crossing soft ground and for the improvement of an existing soft roadbed. It has a rough surface, uncomfortable for passengers and hard on transportation; but the resistance to traction is much less than would be expected, and the rough and slightly yielding surface affords excellent footing for animals. Construction is easy and rapid.

e. Plank roads.—Plank roads are used to provide for the rapid advance of heavy traffic where existing earth roads are unable to sustain it or where the ground is too soft or the time too limited for any other type of new construction; also for turnouts, detours, and parking spaces at supply points where construction is comparatively easy and very rapid. In damp weather, vehicles and animals have difficulty obtaining traction on plank-surfaced roads where there is much grade.

f. Earth roads.—Earth roads are crowned roadways without a hard surface. These are widely prevalent in the United States and constitute a large percentage of the total road mileage. The mileage capable of sustained motor traffic is, however, a small percentage of the whole. In certain seasons of the year earth roads are impassable for motor traffic for considerable periods of time—as high as five months in some sections—and for heavy animal traffic for lesser periods. In the Tropics they are dependable for only about four months in the year.

g. Gravel roads.—On account of the wide prevalence of gravel in the United States a large mileage of this type of road has been built. Natural gravel roads from material as taken from the pit, if reasonably available, can be constructed at a relatively rapid rate, and they are entirely suitable for military traffic, if properly maintained.

h. Macadam roads.—A macadam road is one whose crust is composed of stone or similar material broken into irregular angular fragments compacted so as to be interlocked and mechanically bound to the utmost extent. When it is bound by the aid of water, it is called a water-bound road. Experience gained during the World War indicated that the water-bound macadam road constructed with artificial base on the Telford principle is entirely suitable to bear the heavy traffic of modern war. Its construction is a slow process.

i. Other types.—Concrete and bituminous roads are used for military operations where they exist but new construction with these materials is not undertaken on account of the scarcity of materials, slowness of construction and expert personnel required.

8. Dimensions, gradient, and curvature.—*a. Dimensions.*—A road for a single column of traffic must be 9 feet wide. A road for two columns of traffic must be 18 feet wide. These dimensions include only the metaled surface of the road and do not include the shoulders and ditches. Trails should be at least 4 feet wide.

b. Gradient.—Grades are limited in their maximum by the practicability of the traffic to negotiate them. Steep slopes are very fatiguing to animals. Long steady ascents should be broken by short lengths of easy grade. In the case of motor traffic, the question of gradient does not assume the importance attached to it when animal traction alone is considered. Motor vehicles can negotiate all grades which animal-drawn traffic is required to use, and therefore the latter only need be considered when deciding upon ruling gradients. The wear and tear upon the road caused by motor traffic, however, increase rapidly with the grade and for this reason it is desirable to keep it as easy as possible. The maximum grade should not exceed 10 per cent. The minimum grade should not be less than one-half of 1 per cent in order to provide for drainage.

c. Curvature.—For motor traffic a curve should have a minimum radius of about 150 feet and for animal-drawn traffic one of about 50 feet. A curve at the top or bottom of a hill is objectionable. It is the practice to give roads extra width at curves to facilitate fast traffic. The extra width is provided on the inside of the curve and is eased back to the normal width of the road on the tangent. For military purposes it is sufficient to increase the width on sharp curves, 4½ feet for one-track roads and 1½ feet for two-track roads.

9. Materials.—In order to expedite construction, reconstruction, or repair and to conserve transportation, military road construction utilizes local materials wherever possible. These materials may be earth, gravel, shell, cinders, rock, or timber.

10. Traffic signs.—*a. Necessity.*—Traffic signs, now universally used in peace, are much more necessary in war to guide constantly shifting troops and transport in unfamiliar regions. They are used to mark dangerous curves and crossings; geographical locations, such as towns and villages and the important points therein; crossroads and road junctions, indicating where the roads lead therefrom; the location of and direction to important military centers, such as unit headquarters, depots, parks, dumps, refilling and relay points, airdromes, hospitals, ambulance stations, collecting stations, aid stations, distributing points, railheads, regulating stations, and other establishments. Engineers are equipped to prepare road traffic signs. Road and traffic signs are placed by or under the supervision of the engineers in accordance with the road circulation plan.

b. Character.—Traffic signs should be arranged so as to be unmistakable in their meaning and so simple as to be quickly understood. Their size should be commensurate with their purpose. Signs along a trail used only by foot troops need be no larger than necessary for one to read while walking by, the letters being from 1½ to 5 inches high. On principal roads signs should be large enough to be read from fast-moving automobiles, the letters being from 12 to 18 inches high. The letters should be in sharp contrast to their background; white letters on black background facilitate night reading, although black against white is suitable. If available, luminous paint should be used. Especially important signs should be illuminated by lanterns or electric lights at night if the situation permits. To catch the eye quickly and to aid illiterates distinguishing marks should be used, such as division or arm or service insignia where applicable. Direction arrows should be directive and clear.

Section II

RECONNAISSANCE

11. Kinds of road reconnaissance.—*a.* Road reconnaissance may be one of four kinds:

(1) A reconnaissance for information of roads to be used as a basis for tactical operations.

(2) A reconnaissance to obtain technical data to be used on the basis of engineering road operations.

(3) A location reconnaissance for new road construction.

(4) Periodical inspections.

b. The resulting report depends upon the uses to which the report is to be put and may vary from a simple statement as to the condition and capacity of the highways to a complete catalogue of all information concerning the road net within the theater.

12. Reconnaissance for tactical purposes.—*a. Information desired.*—The reconnaissance to obtain information concerning the roads which is to be the basis for the tactical plans of the commander aims at determining four important facts:

(1) *The location of the roads.*—This information is such as is shown upon an up-to-date map or an aerial photograph mosaic of the area.

(2) *The load-bearing strength of the roads*; that is, whether suitable for general traffic including fully loaded trucks or whether limited to light motor vehicles and animal-drawn vehicles.

(3) *The width of the roads*; that is, whether they will accommodate one, two, or more lines of traffic.

(4) *The condition of the roads*; that is, whether passable or impassable.

In addition to the foregoing, the reconnaissance should bring out in certain situations the location of any critical points at which enemy activity against the roads might vitally affect our operations, and should also determine what roads are visible from the enemy position and hence restricted to night traffic unless camouflaged.

b. The report.—The report of this kind of a reconnaissance is used by the staff in making up tactical plans, plans for the location of supply installations which depend upon roads, and plans for the circulation of traffic during operations. To best serve this purpose, the report should be brief and should present the essential facts graphically, if possible. A very suitable report may be prepared by marking with appropriately colored pencils on a map or on aerial photographs. For example, all roads suitable for general two lines of traffic might be shown in blue; all roads suitable for only animal-drawn traffic might be shown in red; roads which are impassable due to weather, enemy activity, or demolitions might be shown with a broken line.

13. Reconnaissance for engineering data.—The first reconnaissance made to obtain engineering data is similar to the tactical reconnaissance described in the previous paragraph and becomes the basis for the first disposition of engineer troops upon road work. All of the information obtained as for a tactical reconnaissance is necessary for engineering purposes. In addition a more detailed reconnaissance should be made to determine the gradients, especially the very steep ones; the location, condition, and capacity of all bridges and culverts; the kind of surface, whether macadam, gravel or concrete; the dimensions including, if possible to obtain it, the depth of the metal surface; the actual location of the needed repairs together with an estimate of the men, materials, transportation and the time required to effect the repairs; and the location and kind of all local materials such as rock, timber, corduroy, or gravel, which might be used in road work.

14. Location reconnaissance for new road construction.—*a. Hasty location.*—In the forward areas of the combat zone where careful location is prohibited by lack of time and enemy activities, roads and trails are located largely by eye, after personal reconnaissance. In the rear areas of the combat zone the location is as careful as conditions permit, since careful location economizes material and labor. In either case, the road is located by the use of a map, if available, and aerial photographs. If neither of these is available, sketch maps may be made by the usual reconnaissance methods. The location, while primarily such as will satisfy the demands of military operations, aims at keeping the earthwork, cuts, and fills to a minimum and economizing in the haulage of surface materials. The alignment and grade of the road are indicated to the constructing troops by means of stakes on the center line at 50-foot intervals. The cut or fill is marked on the side of the stake.

b. Careful location.—When time is available, the steps in the location of a road are—

(1) *The reconnaissance* with the best available map to determine which of several possible routes should be selected.

(2) *The preliminary location.*—A detailed survey according to the accurate methods of topographic surveying of a belt of terrain on the general route selected, sufficiently wide to include all probable locations. It gives the data for final location and construction. The main traverse is run on the most probable location.

(3) *The final location of the center line of the road* as determined from the map and notes of the preliminary location. This is placed on the map and then staked out on the ground.

15. Estimating earthwork.—The profile of the ground along the center line of the selected route is plotted on profile paper to a convenient scale. In order to magnify the irregularities the vertical scale is taken about ten times the horizontal scale. The axis of the road is then represented by drawing on the profile a line so located as to equalize the cuts and fills as far as practicable and at the same time keep the gradient at any point not greater than the adopted maximum. To estimate roughly the volume of earthwork in cut and fill, cross sections of the route taken in the field at intervals are plotted to scale on cross section paper. The surface and side slopes of the roadbed at each cross section are then plotted, the elevation of the center of the road being read off the profile. The area of the cross section of cut or fill may be estimated by measuring the area thus enclosed with a planimeter or by simply counting the squares of cross section paper embraced within the indicated lines. The volumes of cuts or fills may, with sufficient accuracy, be determined from the end-area formula:

$$V=\frac{(A_1+A_2)}{2}\times\frac{L}{27}$$

Where V=volume of cut or fill in cubic yards.
A_1=area of cross section at one end in square feet.
A_2=area of cross section at other end in square feet.
L=distance between cross sections in feet.

16. Periodical inspections.—Periodical inspections are made in connection with road maintenance. Their purpose is to determine the conditions on all the roads, the density of traffic using the roads, progress of maintenance work, and the results of various methods of maintenance. The resulting reports are used to keep an up-to-date road situation map which is used as a basis both for tactical and supply operations and for the employment of road maintenance troops.

Section III

CONSTRUCTION

17. Fundamental principles.—*a. Construction.*—There are certain fundamental principles underlying the construction of any road, neglect of which will cause trouble in maintenance and repairs, and often failure; they are as follows:

(1) *Drainage.*—The road must be efficiently drained; drainage is its life.

(2) *Foundation.*—The foundation must be well prepared, drained, and consolidated.

(3) The lower course of metal roads, called *base* or *artificial foundation,* must be firm.

(4) The upper course of metal roads in contact with traffic, called *wearing course,* must be hard enough to sustain the traffic and to resist excessive wear.

b. Drainage.—Drainage is accomplished by the following means:

(1) By providing at least the minimum grade, crown, and slope to subgrade, road surface, and shoulders.

(2) By providing side ditches of sufficient width, depth, and bottom grade. Ditches should generally be at least 2½ feet deep, and the bottom should be not less than 1 foot below the subgrade level. To prevent caving they may be revetted with stone, lumber, hurdles, etc.

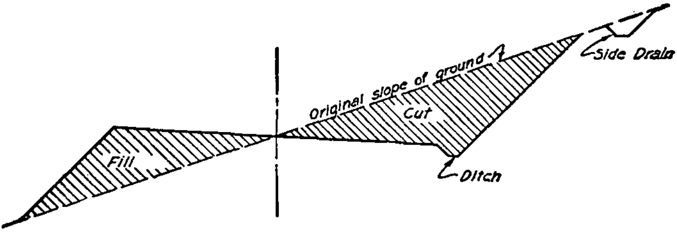


FIGURE 1.—Ditch and side drain

(3) By providing side (catch water) drains along cuts and side hills to intercept the surface water and discharge it at intervals into the ditches or natural watercourses. It may be necessary to revet these to prevent caving. Figure 1 is a typical cross section showing ditch and side drain.

(4) By providing, on clay soils, an impermeable base, to act as a seal and prevent mud working up through the crust, and cross drains across the road connecting the ditches.

(5) By compacting an impervious crust.

(6) By providing bridges and culverts at the crossings of streams and dry runs to care for large quantities of water which cross the line of the road.

18. Culverts.—*a.* On temporary roads these will usually be of the simplest kind. If planking and timbers are available, boxes, square or rectangular in cross section, may be constructed for the purpose. Care should be taken to make them amply strong to withstand the loads passing over them. If galvanized iron pipe is used, it should be covered with at least 18 inches of earth. Wider ditches, up to 12 feet, may be bridged by laying round stringers at least 10 inches in diameter, or 3 by 12 inch stringers, lengthwise of the road and placing on these poles 4 to 6 inches in diameter or 3 by 12 inch plank for decking. Round-pole decking should be covered with sufficient earth, gravel, or sod to form a fairly smooth roadway.

b. Where materials for culverts or bridges can not be obtained, small streams or ditches may be crossed by sloping down the

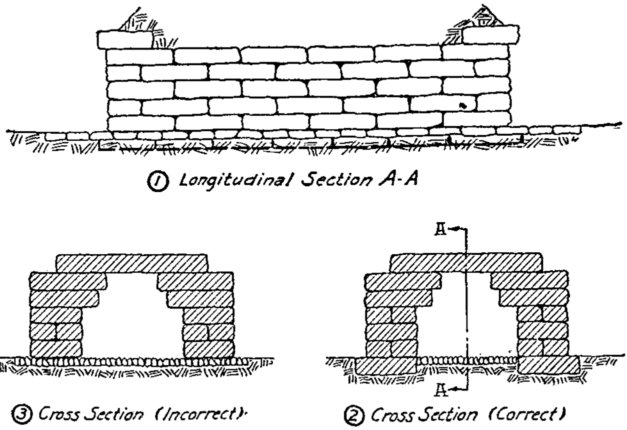


FIGURE 2.—Stone culvert

banks and paving the bottom with large, nearly flat, stones. This method has proved very useful in arid or semiarid regions. Concrete can be used in such cases or large stones, using concrete to fill the voids and to make a smooth surface. To prevent being washed out, paving material should be laid with its wearing surface flush with the general elevation of the stream bed. It is usually advisable to lay riprap on the downstream side to prevent undermining by backwash.

c. In some localities it will be found that a comparatively small amount of water has worn a ravine of considerable size. This occurs where the soil is light and easily eroded after droughts, as in arid climates. In such cases a brief investigation of the drainage area will determine the size of the culvert. Culverts should always be made larger than appears necessary, as otherwise they are almost certain to be too small.

d. The sides of culverts may be revetted by driving stakes and placing brush back of the stakes. In any case, the stringers should have a bearing of not less than 4 feet at each end to allow for erosion of the sides of the ditch.

e. Many formulas have been devised for obtaining the cross section area of culverts and bridges. The more complicated formulas are, of course, the more exact, if all the conditions of rainfall and run-off are known, but this is very seldom the case, even in civil practice, and hence great refinement in such computations is a waste of time. For all military purposes, the following formulas will suffice. For tropical climates where the rainfall is very great, the values obtained from either formula must be increased from 50 to 100 per cent. For arid climates, on the other hand, the values should be decreased, except for hilly and mountainous sections up to 1,000 acres, where local thundershowers, over comparatively small areas, may make demands fully as great as anywhere except in the Tropics.

f. The formula used in the United States between the Ohio River and the Gulf of Mexico, and which is safe for any similar country with similar conditions as to total rainfall and rainfall of storms, is as follows:

$$A = C\sqrt[4]{D^3}$$

A=area in square feet of cross section of culvert.

C=3/10 to 7/10, depending on character of terrain, the smaller for fairly flat country and the larger for very hilly or mountainous country, and intermediate values for intermediate country.

D=drainage area in acres.

Myer's formula is as follows:

$$A = C\sqrt{D}$$

A=area in square feet of cross section of culvert.

C=constant=1.0 for flat or slightly rolling ground; 1.5 for hilly ground; 4.0 for mountainous or rocky ground.

D=drainage area in acres.

This formula is used by the Northern Pacific Railroad across the plains from Minnesota to the Pacific, and is therefore excellent for that or similar territory and rainfall. Figures 2, 3, and 4 show sections of culverts of various types suitable for military purposes.

19. Road structure.—*a. Foundation.*—(1) Soils of foundations may be classed as permeable, impermeable, and solid rock. Permeable soils of sand and gravel give little trouble. On rock

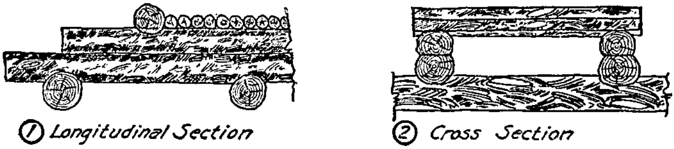


FIGURE 3.—Log culvert

it may be advisable to place a cushion layer of sand to prevent pulverization of the metal. Impermeable clay soils present the most trouble. Water will not percolate through them and must be rapidly drained off. If a clay foundation is allowed to become water-soaked it will quickly be transformed into mud, which will

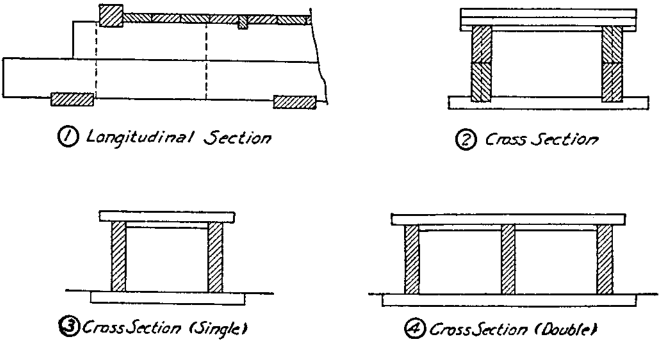


FIGURE 4.—Lumber culvert

work up through the road crust under pressure of traffic and destroy it.

(2) Figure 5 shows typical details of foundation drainage.

(3) Figure 6 shows typical cross sections of covered drains.

b. Artificial foundation (base).—This is the lower course of large metal material typically characteristic of the macadam roads applying the Telford principle. Practice in the United

States varies as to sizes of stone for this course; depth as set on edge varies from 5 to 8 inches; width from 4 to 10 inches; length from 6 to 18 inches. It must be strong enough, and of sufficient elasticity, to bear the pressure of the traffic without permanent displacement or crushing; thick enough to distribute the pressure over the foundation, so that the latter is not stressed beyond its bearing power; and permeable enough to permit water to drain through it to the foundation.

c. *Wearing course.*—This should provide a hard, smooth surface for traffic, a waterproof covering for the road, and a wear-

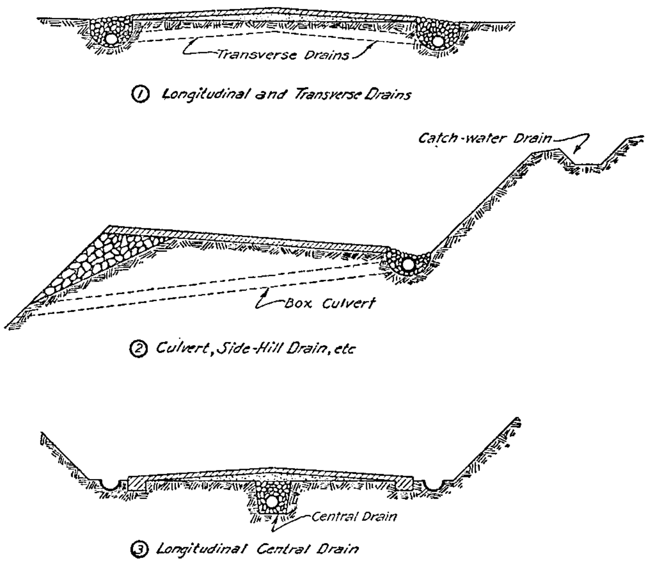


FIGURE 5.—Foundation drainage (cross sections)

resisting medium for the protection of the artificial foundation (base) beneath. For metal roads the harder varieties of rock, such as trap, furnish the best wearing surfaces. Granite requires a cementing material. Limestone is used extensively, due to wide distribution, but it wears rapidly under heavy traffic.

20. Macadam roads.—*a.* The following are the steps in the construction of a water-bound macadam road with Telford artificial foundation:

(1) *Clearing.*—Clear the right of way for the necessary width on each side of the center line of all trees, brush, and other vegetable matter. Trees are cut down with axes and saws or explo-

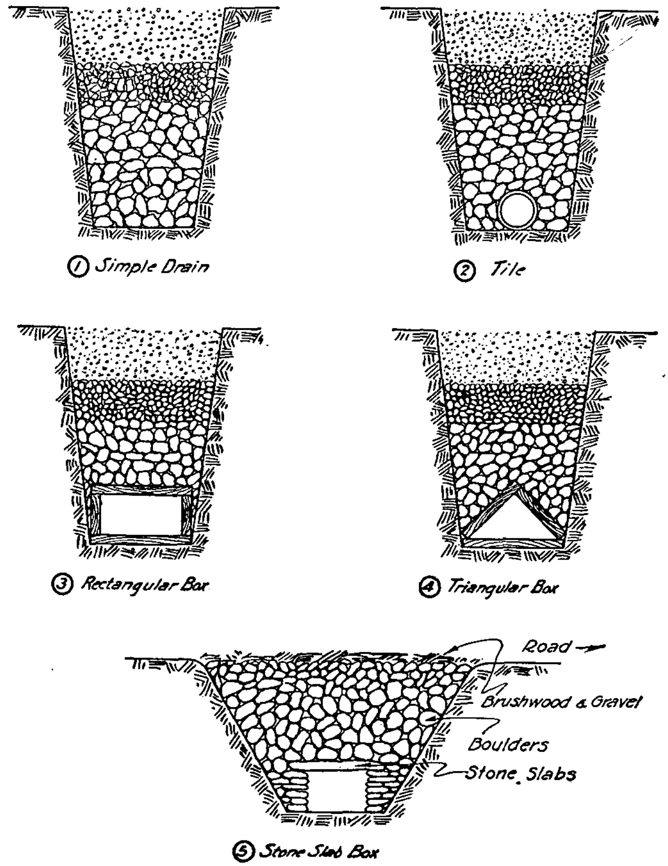


FIGURE 6.—Covered drains

sives, and removed in the most expeditious manner, whole or in sections. When stumps are to be grubbed the trees are usually cut above, but not over three feet from, the ground; if the stumps are to be left, it is customary to cut off the trees at the level of the ground.

(2) *Grubbing.*—Clear the space required for the roadbed and necessary shoulders and side drains by grubbing all stumps and other vegetable matter. In fills over one foot high it is unnecessary to remove stumps that are cut flush with the ground. Stumps may be removed by digging, pulling, burning, blasting, or a combination of these methods. Burning and digging are processes generally too slow for military work. When the stumps are few and small, pulling is a rapid method. This is accomplished by specially constructed stump pullers, by traction or donkey engines, or with animals. For the removal of large scattered stumps, explosive alone is the most rapid and economical method both in civil and military practice. For the removal of large stumps in considerable numbers a combination of blasting and pulling is the most efficient method. Explosives split the stumps which are pulled by tractor or other pullers noted above.

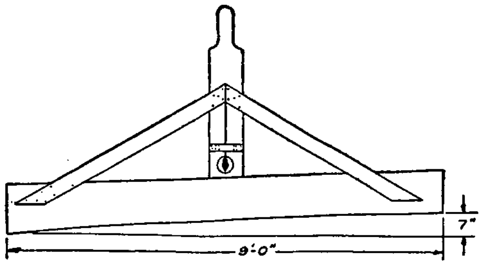


FIGURE 7.—Road templet

(3) *Grading.*—This term comprises all the work preliminary to the finished shaping and includes practically all earthwork. Cuts and fills are made according to survey or sketch notes and data transferred to the grade stakes. Slope stakes mark the limits of cuts and fills. In making fills the earth should be deposited in thin layers, 6 to 8 inches deep, extending from slope to slope, and each layer well compacted either with a roller or by driving over it with wagons in the process of the work. Cuts and fills are made with various types of equipment, varying from pick and hand shovel to steam shovel, steam roller, and large dump trucks. Allowance must be made for shrinkage, which will seldom be less than 10 per cent. For approximate estimates of shrinkage 15 per cent may be used for fills over 2 feet deep and 20 per cent for fills less than 2 feet deep.

(4) *Preparing subgrade.*—The subgrade excavation is usually a shallow trench of which the surface (subgrade) is parallel to the finished surface of the road and of the same width. The sides of the trench, which serve to hold the stone in place, are formed by the earth shoulders at least four feet in width. The subgrade should be brought to true line and grade and be thoroughly compacted with a steam roller. Any low spots which appear during compaction should be brought up to grade with good material and rerolled. The use of a templet is advisable to obtain the crown. Figure 7 shows elevation of the templet for this purpose.

(5) *Ditches and drains.*—These should be executed simultaneously with the subgrade.

(6) *Laying base.*—This consists of large stones of about 8 inches in width laid with their greatest length across the road, breaking joints, largest edge down "and not on the flat" (Tresaguet) with the interstices filled with smaller stone. This course should be rolled when time permits. Hand laying is a very slow process. Telford roads are constructed in the United States by dumping large stones in loose "if the stone is a granite or trap that breaks out in irregular pieces or if cobblestones are used." This method will make a satisfactory road and should be adopted when the time factor demands.

(7) *Completion of crust.*—Lay a 4½-inch layer of broken stone (2 to 2½ inches) and roll thoroughly. If time and materials permit, lay a second similar layer of slightly smaller stone and roll likewise. Finish off the surface by rolling in stone screenings

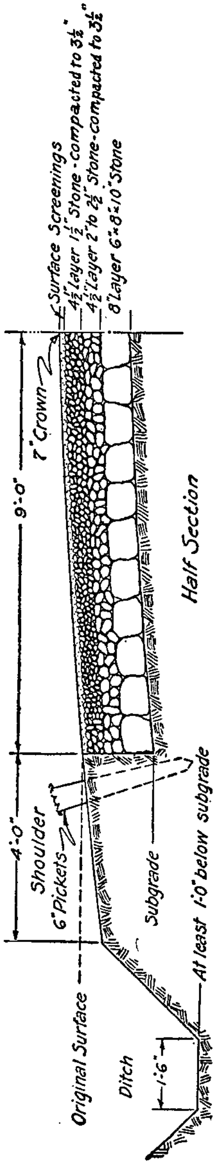


FIGURE 8.—Macadam road, 18-foot

or gravel, and finally sand with water. Rolling is a slow process and may be impracticable; then the road must be compacted under traffic and should be kept shaped up during the process to prevent the formation of ruts and holes, extra material being added where necessary.

(8) *Traffic guards.*—Where shoulders are too soft to permit vehicles, place pickets, large stones, or mounds of earth at inter-

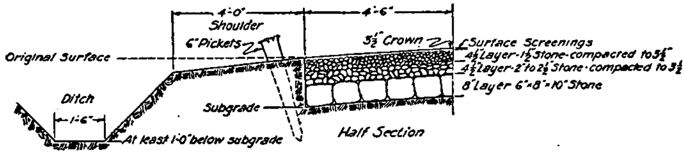


FIGURE 9.—Macadam road, 9-foot

vals on the shoulders at the edges of the metal as guides to keep the traffic off the shoulders and edges; pickets should be inclined outward.

b. Cross sections.—Figures 8, 9, and 10 illustrate the construction as described above of water-bound macadam roads. Excavation may be saved by building up shoulders and foundation with earth excavated from ditches. This requires thorough compacting of loose material, and outer walls of large stones at the edges to prevent spreading of the metal and to retain the shoulders, as illustrated in Figure 10.

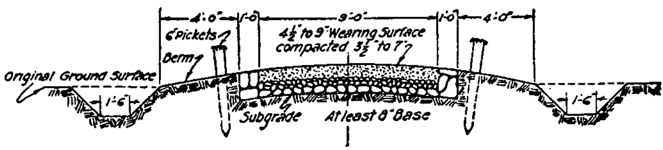


FIGURE 10.—Macadam road (with built-up shoulders)

c. Widening of macadam roads.—This should be accomplished by widening equally on both sides if conditions permit. The earth shoulders should be excavated to a depth sufficient to admit of laying the artificial foundation and wearing surface, and to preserve the camber so that drainage into the ditches is not obstructed. The widening should be carried out only on one side at a time over a section of the road. The bonding of the new portions with the old is very important and care should be exercised to prevent the formation of a ridge that will hold water on the surface. Figure 11 shows the method of widening a 9-foot macadam road to 18 feet.

d. Expedients with metal.—In an emergency some type of tread road will frequently serve the purpose. This may be macadam, in which case the road metal is placed in parallel trenches, one for each wheel tread. Trenches 12 inches deep by 30 inches wide are usually sufficient. This type of macadam road requires about half the material and labor of a macadam road. The tread road may be made of large paving stones placed flat on the surface of roughly prepared ground. Either type of road may

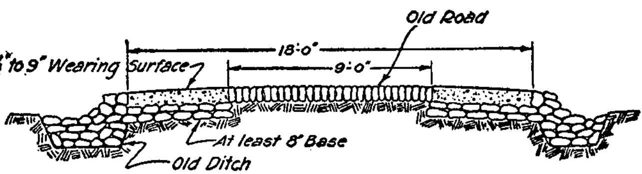


FIGURE 11.—Widening old road

be widened and completed by throwing stone between and outside the tracks. Old toll tread roads in New Hampshire were constructed of stone slabs 2 feet square and 4 inches thick, with the space between filled with cobble stones. Drainage should be provided as soon as time and labor permit. A properly ditched and drained tread road meets most of the requirements for detours and extensions in the forward areas. Turnouts should be provided to care for passing and disabled vehicles. Brick, paving stones, or any other road metal may be used in

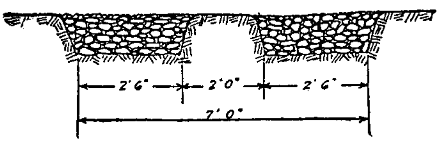


FIGURE 12.—Metal-tread road

the construction of the tread road. In its simplest form it involves merely clearing out the wheel tracks and filling with some type of road metal. This type of road is particularly adapted to the hand tools carried by engineer troops. More rapid excavation can be obtained by plows and scrapers or by small trenching machines. Figures 12 and 13 show cross sections of a metal-tread road and a concrete-tread road.

e. Time saving.—To construct a macadam road with any degree of rapidity, machinery must be used to the utmost, deliveries of stone must be made in large capacity dump trucks, and the work must be so organized as to proceed simultaneously at a number of different points. Operations should overlap; grading should begin as soon as clearing has created working space; deliveries of stone should begin as soon as grading has progressed far enough to permit it, etc. When rock delivery can be made at one working head only, the time of construction is considerably slowed up. By compacting under traffic much time is saved.

21. Gravel roads.—The roadbed is prepared in accordance with the time available. The gravel may, in emergency, be placed on level ground upon the natural surface and compacted under traffic. For heavy traffic a 10-inch crust should be provided. When the natural material is deficient in binding elements, clay may be added. Figure 14 shows a typical cross section of a gravel road as built in the United States. In emer-

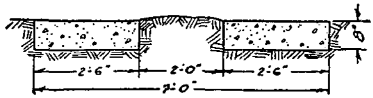


FIGURE 13.—Concrete-tread road

gency work, time may be saved by the construction of a gravel-tread road.

22. Earth roads.—*a. General.*—In general, it may be said that earth roads are not suitable for continuous military traffic. The supporting power of cohesive, compacted earth, moist but not wet, is sufficient to bear, without objectionable indentation, the weights on hoofs and wheels which result from ordinary animal-drawn transportation and very light motor transportation. However, when wet, the supporting power of the same earth is insufficient. Nevertheless, earth roads under favorable conditions may support military traffic for a limited but very vital time, and the earth road itself constitutes a subgrade for later improvement by the application of metal surface. The quality of the earth has a great influence upon its behavior in the road. Clay compacts well, but will not drain. Sand drains well, but usually will not pack. A road which is too sandy may be improved by an admixture of clay and, conversely, a clay road may be improved by an admixture of sand.

b. Cross section.—The cross section of an earth road depends upon the character of the earth. Clay soil requires a high crown

1¼ inches per foot of width; sandy loam requires a crown of 1 inch per foot of width. Ditches and cross drains are required as for other types of road.

c. Construction.—The construction of an earth road is accomplished on level terrain by digging the side ditches and casting the earth toward the center of the road to form the crown. This work may be done by men with picks and shovels or by the use of harrows and scrapers drawn by animals. The scraping grader is a scraper mounted on wheels and adjustable as to height. It hangs obliquely over the road, the outer end in advance, so that the surplus earth is pushed toward the center. In the Southwest, during dry seasons, earth roads are sometimes constructed by removing the top layers of dust and soil and using the firmer surface thus exposed, for the roadway. These roadways require frequent removal of dust and loose material.

23. Plank roads for motor transportation.—*a. General.*—To sustain motor transportation a plank road must be of sub-

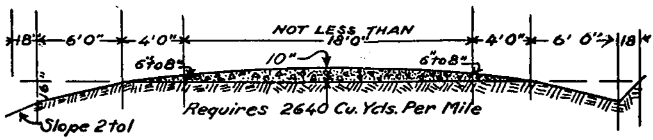


FIGURE 14.—Typical gravel road

stantial construction; to facilitate supply and construction, the materials and their dimensions should conform to standard commercial practice. Hardwoods are best but are not plentiful, and are expensive and difficult to work and handle. Yellow pine is an entirely suitable material. Floor planks 3 to 4 inches thick 10 to 12 inches wide, and 10 feet long are desirable. The 10-inch plank is easier to handle than the 12-inch and for this reason is preferable. Experience gained in the World War shows that an initial camber of 4 to 6 inches in the center of an 18-foot road or 2 or 3 inches between edges of a 9-foot road is essential; in the wider road the camber finally adjusts to 2 or 3 inches. Floor planks should be spiked to stringers; nailing may be done in emergency, but will not hold, will split hard plank and should be followed by spiking. If a plank road is later to be widened, care must be exercised so that this will be feasible; in some cases it may be found desirable to make two separate roads. The foundation must be shaped to a plane surface so as to provide a good even bearing for the stringers. The stringers settle into the subgrade and the roadway planks finally bear on the ground between them. It is therefore important to have the subgrade smooth so that settlement will not loosen the planks from the stringers. Corduroy or fascines may be used for foundations where the ground is soft.

b. Construction.—The following are the steps in the construction of a plank road to sustain motor transportation:

(1) Clear and grub the right of way.

(2) Stake out center line.

(3) Stake out side ditches, leaving a shoulder 4 feet wide on each side of the roadway.

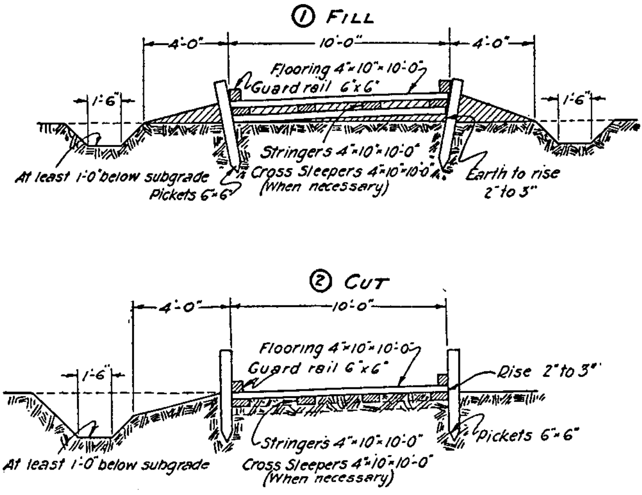


FIGURE 15.—Plank road for motor transportation

(4) Grade the foundation so as to provide a 4 to 6 inch rise at the center for an 18-foot road, or 2 to 3 inch rise on one side for a 9-foot road.

(5) Lay the stringers, lining them up carefully in regular rows on about 3-foot centers, breaking joints.

(6) Lay floor planks close together, bore ⅜-inch holes for spikes, and spike planks with one spike to every stringer. Stagger spikes.

(7) Spike guard rails, with 12-inch gaps between, on each side.

(8) Place pickets at 15-foot centers.

c. Cross section.—Figures 15 and 16 show cross sections of plank roads; all are suitable for motor transportation.

24. Plank road for animal-drawn transport or passenger cars.—*a.* (1) *General.*—To sustain animal-drawn transportation or passenger cars, a plank road may be of lighter construction, built as follows: Double lines of 4 by 6 inch stringers are laid flatwise, 2 or 3 inches apart, well bedded and breaking joints; inner edges of these lines of longitudinal stringers will be about 4½ feet apart, for use with planks 8 feet long. These floor planks should be 2 inches thick and 10 or 12 inches wide, laid lightly touching, if wet, or one-fourth inch apart, if dry; each plank should have two

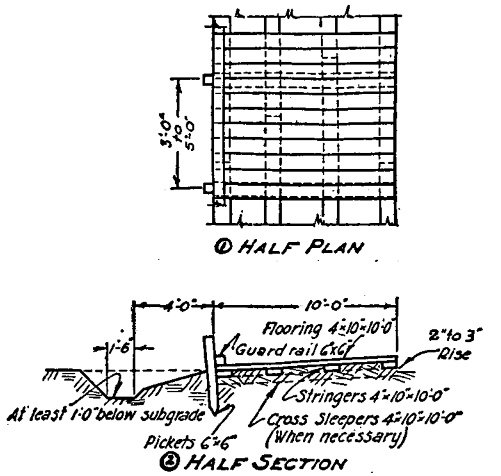


FIGURE 16.—Plank road for motor transportation

spikes or nails to stringers in each end. Planks should be offset in blocks of about 20 to facilitate getting back a wheel which has run off the road. (See fig. 17 ①.)

(2) *Alternative construction.*—Under certain conditions each pair of 4 by 6 inch stringers may be replaced by one 2 by 12 inch stringer, bedded in the ground. (See fig. 17 ②.)

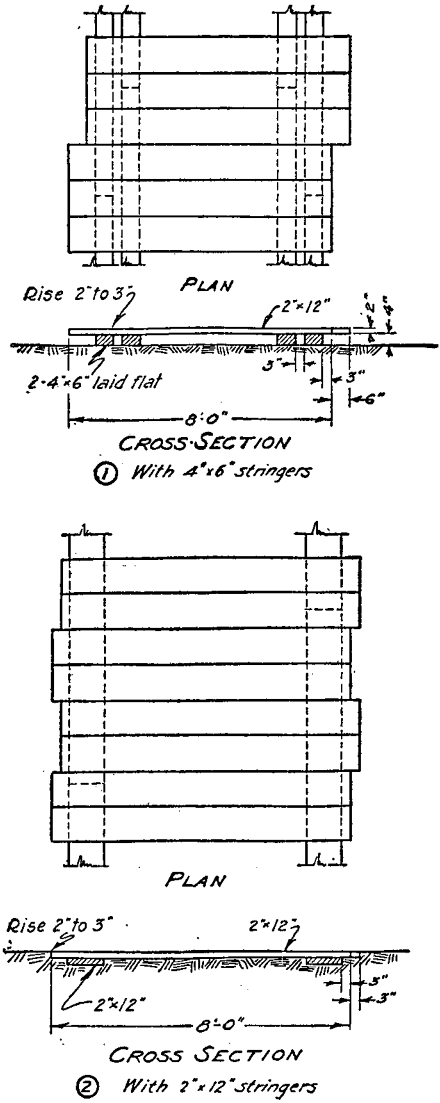


FIGURE 17.—8-foot plank road, animal transportation

b. Plank road for two columns of traffic.—A 16-foot road is shown in Figure 18. It is common practice to lay two separate roadways, each 8 feet wide, rather than one 16 feet wide, as in the latter case vehicles tend to use the center of the road, causing excessive wear.

25. Important points in construction of plank roads.—The following are points of importance in constructing plank roads:

a. In swampy ground a layer of fascines or corduroy placed under the stringers improves the foundation.

b. Camber should be provided.

c. Shoulders should be at least 4 feet wide.

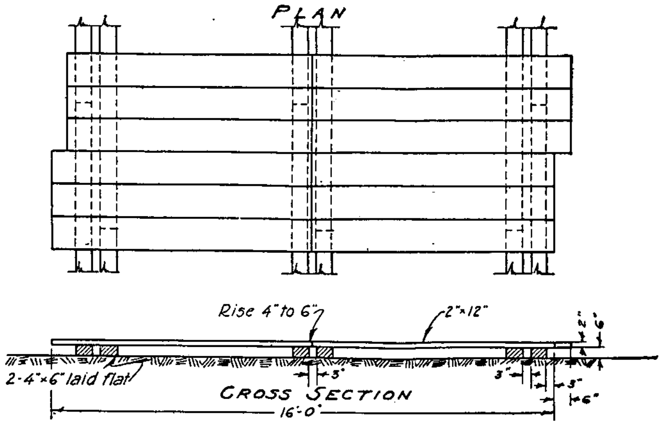


FIGURE 18.—16-foot plank road, animal transportation

d. Ditches should be revetted with brush, plank, or netting, when necessary.

e. Earth, sand, and gravel are necessary in wet weather to prevent skidding.

26. Time factor in the construction of plank roads.—The time factor in the construction of a plank, as of any military road, is so dependent upon a number of different conditions that no hard and fast rule can be laid down. Under very unfavorable conditions in Flanders it was roughly estimated that, over broken, shelled and low ground, 1 skilled pioneer, served by 4 additional

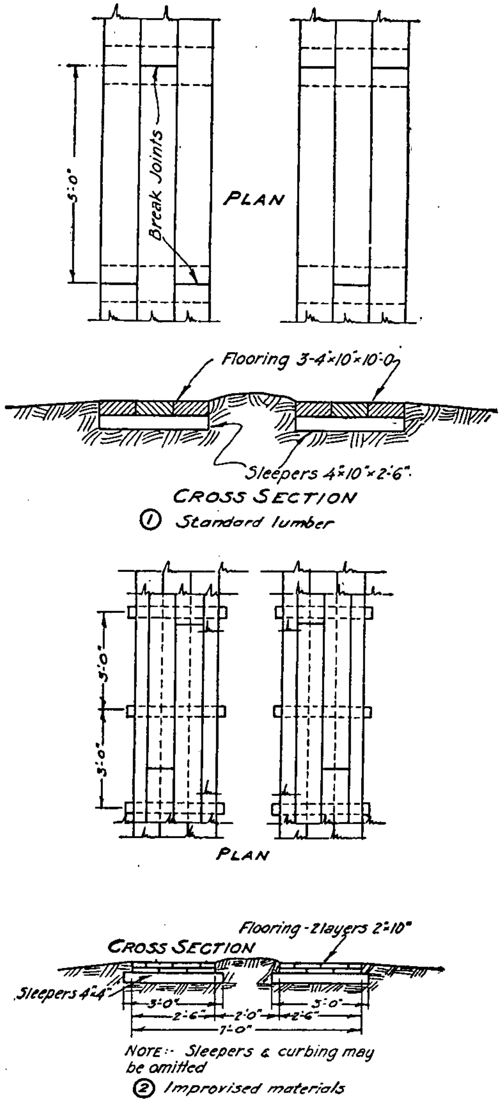


FIGURE 19.—Plank-tread road

carriers, could construct 1 yard of 9-foot plank road per day. The French used a similar type of plank road, which was indeed their normal method of making detours around damaged sections of the road in the forward areas. Under these conditions they estimated that 60 engineers could construct about 400 yards in 10 hours.

27. Plank-tread roads.—To sustain either motor or animal-drawn transportation some form of tread road may be con-

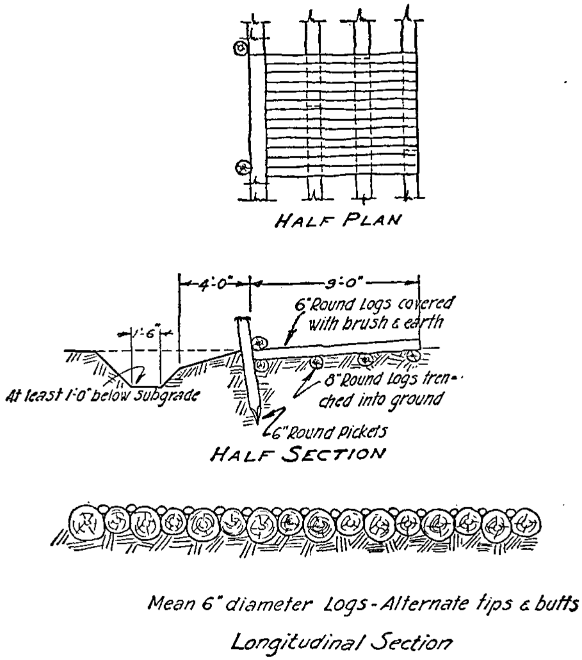


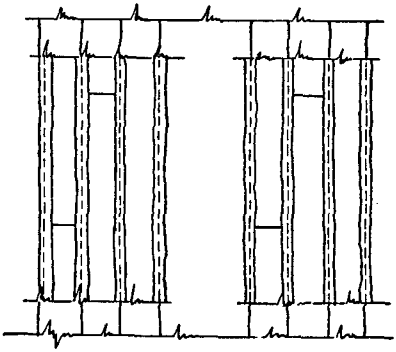
FIGURE 20.—Corduroy road

structed. Two parallel trenches may be dug and the plank tread laid therein on short cross sleepers; or sleepers 7 or 8 feet long, embedded or not, may be laid transversely and treads nailed or spiked to them. Figure 19 ① shows the plan and section of a plank-tread road laid in trenches, and ② shows the same for one of improvised materials.

28. Corduroy roads.—*a.* Where timber is procurable locally a corduroy road may be built over soft ground or over an existing soft road. This type of road is constructed by laying logs, split or round, crosswise of the road either on the natural surface or on longitudinal stringers. In the latter case the surface logs should be spiked to the longitudinal stringers with ½-inch spikes 8 to 10 inches long at the rate of one per log per stringer. The logs should be nearly of the same size and should touch, butts and tips alternating. If the logs are large the spaces may be filled with smaller poles. The bottom tier of logs should be evenly bedded, should have a firm bearing at the ends and should not ride on the middle. The filling poles should be cut and trimmed to lie close. If the soil is only moderately soft the logs need be no longer than the width of the road; in soft marsh it may be necessary to make them longer. The logs may be utilized as the wearing surface, and this is usually done. They make a rough surface, uncomfortable for passengers, and hard on transportation, but the resistance to traction is much less than would be expected, and the rough and slightly yielding surface affords excellent footing for animals. Surface corduroy is very perishable. In marshes, where the logs can be placed below the ground water level, they are preserved from decay, and if any suitable material can be found to put a thin embankment over them a good permanent road may be made. Figure 20 shows the plan and cross section of a corduroy road laid on longitudinal stringers and also the longitudinal cross section of one laid on the natural surface.

b. Any tough, fibrous material may be used to harden temporarily the surface of a road. Hay or straw, tall weeds, corn, and cane stalks may be employed to good advantage. Such materials should be laid with the fibers crosswise of the road and covered with a thin layer of earth thrown on from the sides; in sand, it is better to dig a shallow trench across the road, fill it with the available fibrous material, then dig another trench just in front of and in contact with the first, throwing the sand from it back onto the material in the earlier trench. Other substitutes for logs are fascines, hurdles of brushwood, mats of saplings, etc.

c. A type of road suitable for construction over tidal marshes or swamps subject to overflow is described as follows: Large logs with tops and bottoms adzed are laid in three rows as longitudinal stringers, the outer rows being about the tread distance apart. The space between stringers is ballasted with stone or gravel and across them is laid the corduroy flooring about 6 inches in least diameter. Guard rails of lumber are spiked to piles driven 6 feet into the ground at intervals and extending about 4 feet above the road surface. Against the outside of the guard rails an earth bank is carefully thrown up and consolidated. On the inside of the guard rails an earthen bank is formed. The space between the guard rails is then filled with stones to the



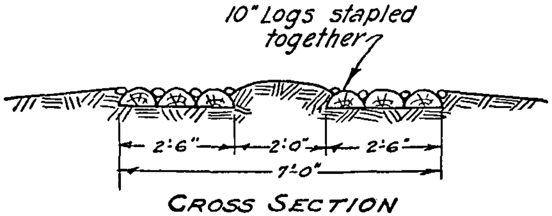


FIGURE 21.—Corduroy-tread road

required level, and shell, gravel, or similar material is spread and compacted to form the wearing surface.

d. A tread road of corduroy is more difficult to build than one of plank. Where split logs are used the road is similar to a plank-tread road. Logs should be firmly wired or dogged together to act as one mass. Where brush and short material are available, the material may be laid transversely for each tread. The construction of a tread road with long material requires careful bedding of longitudinal timbers; logs should be staggered in lengths. Figure 21 shows such a road.

29. Wire-mesh roads.—The netting is the ordinary chicken wire 3 feet wide. Four widths of netting make a roadway about 12 feet wide; the rolls are fastened together with plain wire as laid. One layer has been found sufficient for light traffic, animal-drawn, and for passenger cars. Three layers will sustain motor trucks for short periods in an emergency. Wooden anchoring pickets are attached with plain wire to the outer edges of the netting, and are driven at the bottom of holes about 2½ feet deep along the sides of the track at about 6-foot intervals. When the holes are filled, the tops of the pickets should be well buried, to prevent tripping and damage. Traffic should never be allowed to cross a wire-mesh road at right angles. Plank or other suitable construction must be used at crossings. The wire-mesh road may be used in conjunction with brush or grass, producing a

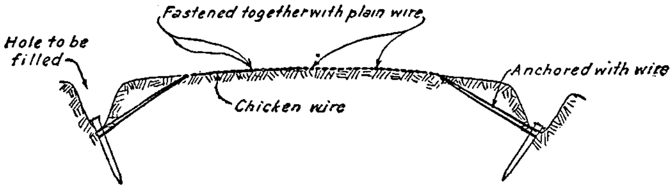


FIGURE 22.—Construction, wire-mesh road

combination corduroy and wire-mesh road. Figure 22 illustrates the construction of a 12-foot wire-mesh road.

SECTION IV

MAINTENANCE AND REPAIRS

30. General.—In the forward areas of a theater of operations, the maintenance of the roads may present great difficulty to the corps and division engineers. Shortage of transportation, deficiency of equipment and, above all, a lack of time will usually combine to make it impossible to undertake any new road construction or even to carry out repair and maintenance work except of the simplest kind. Such conditions may be assumed as normal for the forward areas in a war of movement. Where such situations exist, road maintenance will ordinarily be reduced to ditching for drainage and to spreading by shovel the gravel hauled from local pits. A shortage of transportation will often make it impracticable to secure a sufficient supply of proper patching material and will therefore require the use of material near at hand that would not be considered suitable in civil engineering practice. The following paragraphs should be read with the foregoing statements in mind. Maintenance work must usually be done so as not to interfere with traffic.

31. Organization.—*a. Maintenance.*—In war more than in peace the life of a road depends upon thorough maintenance and the proper organization and equipment to effect it. The force employed upon maintenance will depend upon the nature of the traffic, its intensity, and the character of the roads. There are two systems of road maintenance in common use in civil practice, known as "patrol" and "gang" maintenance. In the former a definite and comparatively short section of road is assigned to a small party, one or more men, who constantly patrol the section and make repairs, on the theory that these should be made as early as practicable. In the latter a comparatively long section of road is assigned a large maintenance gang, who go over the road at infrequent intervals and make repairs. In civil practice the patrol system is now generally adopted. On military roads the patrol system must be used, but the patrol is of such a size as to warrant the designation "maintenance party." Engineer units are assigned to the maintenance of sections of road or to the road net in a given area. The road or road net is subdivided among the working units according to the amount of road that can be covered, due consideration being given to the men and equipment available, the messing facilities for the men, and the control of the command. For continuous maintenance night and day, a combat or general service platoon could be assigned about 5 miles of road.

b. Repairs.—In spite of all maintenance precautions, a road will finally reach the stage where some more radical treatment is necessary. If it is an 18-foot road or wider, repairs can usually be made by treating it one half at a time. On 9-foot roads it is necessary, and on 18-foot roads desirable, to detour traffic for a sufficient period of time to effect the necessary repairs. Where roads have been destroyed by enemy action, this becomes a necessity. The troops assigned to a section of road can usually make minor repairs under the maintenance system; more elaborate repairs must be made by the temporary assignment of additional means or the utilization of the engineer reserves of the maintenance unit, and extensive repair must be treated in many respects as a road construction job in itself.

c. Materials.—Maintenance materials are placed in small piles alongside the roads, to be used as needed by the maintenance party. Under ordinary traffic only two or three tons of material per mile per day are necessary and this may be carried along in a truck or in wagons accompanying the maintenance party. Under heavy traffic in bad weather or under shell fire the requirements in maintenance material may run about 50 tons per mile per day.

32. Macadam roads.—*a. Maintenance.*—(1) *Tools and equipment.*—Each maintenance party should be furnished with a sufficient number of the following tools and equipment: Hoe, road broom, shovel, pick, road rake, scythe, wheelbarrow, tamper, sledge, roller.

(2) *Drains.*—The most important consideration in the maintenance of any road is to keep off the water. To this end particular attention must be paid to keep the ditches and drains open and the water running, by removing all obstructions, such as mud, rock, and vegetable matter.

(3) *Road crust.*—(*a*) *Mud.*—Mud is the greatest destroyer of the surface due to the fact that it holds water on the surface. It must be eliminated at all costs. The best time to effect this is when the surface is wet. The mud is then fluid and may be removed by broom, hoe, or shovel. Vehicles and animals coming from adjacent fields should be required to enter the road at certain points where rough platforms of round logs, called cleaning racks, have been built. A permanent cleaning detail should be located at these racks.

(*b*) *Potholes.*—Potholes are best repaired also when the road is wet. On roads having a hard crust, such as trap or dolomite, throw small broken stone ¾ to 1¼ inches into the hole. Then throw some good binder (usually any earth alongside the road) on the rock, about one of binder to two of stone. When traffic will permit, cut out the hole square with a pick, remove loose material, and fill with metal; then tamp by hand or roll with roller. In the case of limestone or similar soft material it is generally not necessary to cut out the holes.

(*c*) *Clay treatment.*—Metaled roads (particularly those of hard, flinty material) should be covered during dry seasons with a thin coat of clay to prevent disintegration, when a tar preparation is lacking. Scrapings from the road, rock screenings, or even light earth may be used when clay is not available.

(*d*) *Tarring.*—A layer of tar spread on hot, or cold, if mixed with heavy oil (2¾ to 3⅔ pounds per square yard) is very efficacious in preserving a metaled road.

(*e*) *Snow.*—Snow is best removed from a road by a snow plow operated by a tractor or by an improvised plow as described in paragraph 50. When there is sleet or when the snow is compact, the surface should be sanded. If sand is not available, sprinkle light earth or scatter branches or twigs over the road surface.

(*f*) *Thaw periods.*—During periods of thaw the resistance of the road is considerably reduced. This softening is a function of the thickness of the crust, location, nature of the subsoil, drainage, and other factors not always known. Study of a road is necessary to learn the weak sections. Thaws cause an upheaval of the road metal. If heavy vehicles use the road during this period of instability, the surface is easily rutted and liquid mud works to the surface from the foundation. The road is literally destroyed. It may be necessary in certain areas to issue rations to tide over the thaw and to keep traffic at a minimum. During periods of thaw careful attention must be paid to side ditches, and sumps must be constructed where necessary. The only certain remedy is to restrict traffic rigidly. Orders should be promulgated prior to the danger period. The only vehicles that should be authorized on the road are escort wagons and touring cars. The latter should be held to 15 miles per hour. Heavy loads may cause the complete destruction of the road, requiring its reconstruction. Drastic measures should be taken to enforce the traffic regulations. The reconstruction of a road destroyed by thaw should not be undertaken while the foundation is soft.

b. Repairs.—A general resurfacing may be undertaken because the surface is worn down in the center or because the potholes are so close together that repair of individual holes is impracticable. In either case it is best to scarify the old surface by handpicking, by means of a scarifier drawn by tractor, or by a roller fitted with scarifier. After scarifying remove loose material, which should be sorted and used again in resurfacing if it is similar to the new metal; if not, it may be used in patching. It will generally suffice to remove the metal to a depth of 3 or 4 inches only. After scraping and properly shaping the surface, fill the chuck holes and tamp them so that they will not settle and reappear under traffic conditions. Then spread the new metal and compact it. Where edges of the new and the old surfacing join, the junction should run oblique to the axis of the road, so as to minimize the shock in passing from one to the other.

33. Gravel roads.—*a. Maintenance.*—Under continuous traffic a gravel road will be maintained by the same methods as a macadam road. When sections can be relieved of all traffic, or when the width permits, a light blade grader or a road drag may be used. Figure 23 shows a type of drag suitable for this purpose. The principal objectives are to keep the drainage open and to preserve the metal to proper crown.

b. Repairs.—These are made by the use of the grader and drag, as in maintenance, adding to the surface the necessary new metal to preserve the desired thickness of crust.

34. Plank roads.—*a. Maintenance.*—The principal precautions here, aside from drainage, are to replace broken lumber and to keep old parts, especially the floor plank, well spiked down.

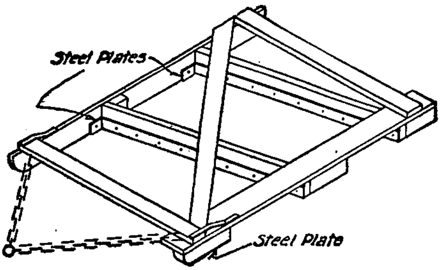


FIGURE 23.—Drag for gravel roads

Sand, gravel, earth, or similar material must be thrown on the surface in wet weather to prevent skidding.

b. Repairs.—If maintenance is properly kept up by replacing broken and worn-out plank, no radical repairs will become necessary. If required, traffic should be detoured and the road reconstructed as originally built.

35. Corduroy roads.—*a. Maintenance.*—These require constant replacement of broken timber, and respiking. The brush and earth surface must be maintained to prevent skidding.

b. Repairs.—The same remarks apply as in the case of plank roads.

36. Earth roads.—*a. Maintenance.*—Earth roads are maintained by proper attention to ditches and drains and by preservation of the crown. Ditches are kept open by handwork or by the use of scrapers or road graders. The crown is best preserved by use of the road drag.

(1) *Construction of the road drag.*—The road drag may be made of split logs, railroad ties, or sawed planks, as shown in Figure 24. Logs should be split fairly straight, although a twist of 4 inches is allowable. The drag should be light so that the driver, as he rides standing, may by shifting his position cause the drag to cut or deposit material as he chooses. A platform for the driver may be made of boards fastened to the bars connecting the logs. The iron shoe projects ½ inch below the log at the forward end of the drag and is flush with the log at its center. The chain is long enough to allow a considerable amount of adjustment in order to make the drag cut more or less as desired.

(2) *Purpose of the road drag.*—The purpose of the drag is to increase the crown of the road and make the surface smooth by

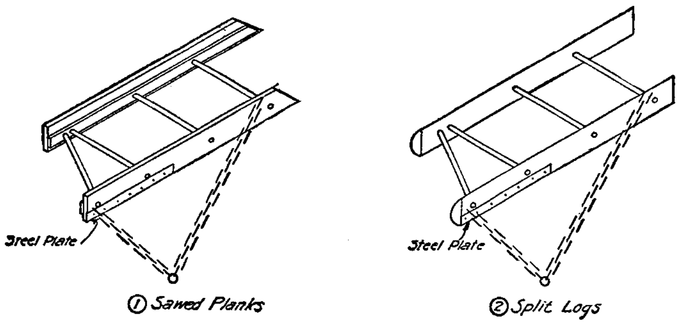


FIGURE 24.—Drags for earth roads

filling in ruts and holes with the material removed by the drag from high points, thus also hastening the drying out of the road. On uncrowned or poorly crowned roads, its use is advisable, but the results are not so good as on crowned roads. It is intended for use on earth and sand roads, and not on macadamized or stony roads. Dragging should take place after a rain but not until the material has dried sufficiently to be no longer mud and before it becomes dust. The drag should always be used so that the portion of the log shod with iron is in front next to the ditch. No extra weight need be placed upon it, except that the driver may stand upon it. The doubletrees should be so attached to the chain that the drag will make an angle of from 45° to 60° with the center line of the road. It should be remembered that the longer the chain the more the drag will cut, while the shorter the chain the less it will cut. In order that this quality of the drag may be made use of, the chain is of sufficient length to allow for considerable adjustment. The driver, by shifting his weight from one end to the other and from front to rear, causes the drag to take up more or less earth and later drop it into ruts, chuck holes, and other places, where needed.

b. Repairs.—Proper maintenance with grader and road drag takes care of an earth road. Drains and culverts, if of log or lumber construction, must be replaced at intervals. These go to pieces very rapidly in wet climates.

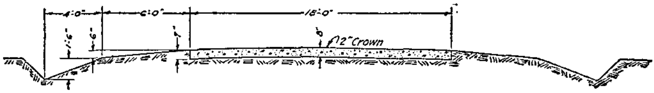


FIGURE 25.—Concrete road

37. Concrete and brick pavement roads.—*a. Maintenance.*—Figures 25 and 26 show typical cross sections of concrete and brick pavement roads. The maintenance of these roads consists in cleaning dust and debris out of the cracks and filling them with tar or asphalt.

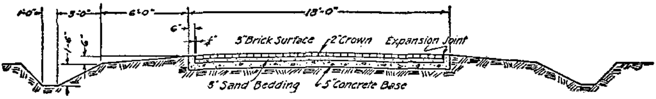


FIGURE 26.—Brick road

b. Repairs.—Minor repairs to a concrete road are made with cement or bituminous concrete; to a brick road by replacing individual bricks. If extensive repairs become necessary, damaged sections must be reconstructed in accordance with original specifications. In the maintenance and repair of concrete roads during military operations, the use of a quick-hardening cement is desirable. A badly broken up concrete or brick road may be maintained as a rough macadam road, using a binder where necessary.

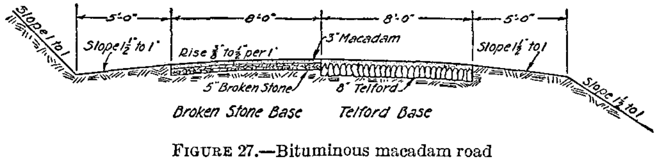


FIGURE 27.—Bituminous macadam road

38. Bituminous macadam roads.—*a. Maintenance.*—This type of road is patched by loosening the stone in the area affected, adding new stone as needed, and then pouring on the necessary amount of bituminous material to coat the stones. Allowance must be made for the compression of the material by tamping, so that a depression does not result. The stones are carefully tamped in place and covered with chips which are also tamped. Figure 27 shows a typical cross section of a bituminous macadam road constructed by the penetration method.

b. Repairs.—Repairs are accomplished in a manner similar to those to a macadam road, using the necessary bituminous material as in the original construction.

39. Repairs in forward areas of the combat zone.—*a. Damage.*—(1) An enemy in retreat will do all the damage he can to the road system, in addition to that resulting from shell fire and use. The amount of damage encountered will depend upon the military situation. In a retreat from a stablized situation this will be very great. In a forced retreat in mobile operations the time is lacking to undertake any great destruction. In the time available, the enemy will destroy sections by blowing up culverts and bridges and the roadway especially at crossings and in towns. He will also fell trees and telegraph and electric light poles across the road and effect the demolition of buildings located near it.

(2) The problem confronting the military engineer is to get the traffic forward at the earliest practicable time, using local materials. Temporary detours, bridges, and culverts are constructed and all obstacles removed. Some form of tread road will frequently suffice for a temporary detour. The original road is repaired as rapidly as possible but this is subsidiary to the expedients to keep traffic moving.

b. Obstructions.—The first mission of division engineers accompanying the advancing troops is to remove obstructions from the roads. Abatis of trees should be dragged aside so as to provide a passageway of about 9 feet and later removed by sawing up or otherwise. A similar passageway should be opened up through the ruins of towns. If the walls on only one side of the road are demolished, open the road along the side which is intact. With the material available from the ruins, build a curb 1 foot high and about 2 feet from any projections which might strike vehicles in passing. In case both sides of the street are damaged, open a passage down the center, if it can be made wide enough for trucks. A sign should be placed at the entrance to the street plainly visible to all, showing the available width of roadway and entrance should be denied to all vehicles that might become stalled. Ruins apt to be shaken down by the vibration of traffic should be demolished and cleared.

c. Delayed-action mines.—In case the enemy has undertaken systematic demolitions, particular attention should be paid to vital areas and important crossroads left intact. The search for delayed-action mines and firing leads should be made systematically and cautiously by specially equipped details of engineers. The enemy may place mines with delayed-action

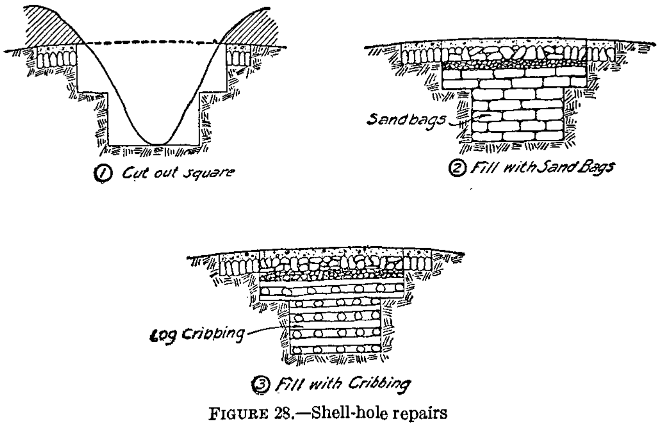


FIGURE 28.—Shell-hole repairs

primers which may not explode them for days or even weeks. One device for delaying firing is a percussion pin held by a wire which is immersed in a corrosive acid. A large mine may be placed under the roadway in a case, the lid of which is supported on pins which are bent down under traffic until closing of the lid fires the charge mechanically. In removing old lead wires care should be taken not to relieve the tension; the wire may hold a counterweight that will fire a primer.

d. Trenches.—Firing and other trenches cut into the road are relatively narrow and may be filled with near-by earth. Foreign substances, such as wood, manure, bottles, etc., should not be used. When necessary, time may be saved by using sandbags. Surfacing material may be improvised from fascines, logs, planks, or débris from buildings.

e. *Shell holes.*—A small shell hole may be repaired in a manner similar to a pothole, first cutting the material out square and then refilling with tamped metal. A large shell hole is also cut out square and the débris removed, the earth is thoroughly rammed, and the excavation up to subgrade filled with sandbags, fascines, timber cribs, or other similar expedients.

f. Mine craters.—Large mine craters are generally of such size as to remove the entire road surface, and may be as great as 115 feet wide and 35 feet deep. The first step is to construct a detour of débris, corduroy, fascines, or plank. The crater hole is then repaired as follows:

(1) Remove all mud and water.

(2) Fill up to within about 2 feet of the road surface with layers consisting of alternate courses of sandbags filled with dry earth and properly laid, and of rammed dry earth.

(3) Fill up flush with roadway with broken stone well tamped, or lay a plank roadway.

(4) It has been found that by placing lightly filled sandbags in craters with wire netting or expanded metal on top and then covering with 3 or 4 inches of road metal, a practicable passage for motor trucks can be made. Any hard material available should be used for filling the top portion of the crater, while the bottom part may be filled with softer material, should necessity demand it.

Section V

REFERENCE DATA

40. Data on road work.—The following data are useful in determining quantities and the time element in military road work. All construction data must be used with judgment.

TABLE I.—*Clearing and grubbing*

Width, feet	Man-hours per 100 lineal yards		
	Light clearing	Medium clearing [1]	Heavy clearing
30	10–40	40–105	105– 630
40	14–55	55–140	140– 840
50	18–70	70–175	175–1, 050

[1] In the eastern part of the United States the average for this class of work is about 350 man-hours per acre.

TABLE II.—*Loosening earth*

Rates in cubic yards per hour; place measure		
Material	Man with pick	2-horse plow
Cemented gravel or stiff clay	1. 4	20
Strong heavy soil	2. 5	30
Common loam	4	40
Light sandy soil	6	60

TABLE III.—*Excavation with pick and shovel*

Cubic yards per hour per man to depth stated				
	0 to 3 feet	0 to 5 feet	0 to 8 feet	0 to 10 feet
Sand	2. 12	1. 81	1. 51	1. 36
Gravel, loose	1. 54	1. 37	1. 18	1. 08
Earth	1. 28	1. 17	1. 05	. 97
Light clay	. 89	. 81	. 73	. 67
Dry clay	. 64	. 59	. 54	. 51
Wet clay	. 54	. 51	. 47	. 44
Hardpan	. 46	. 44	. 42	. 39

TABLE IV.—*Excavation with steam shovel (three-fourths cubic yard)*

Shallow excavation in cubic yards per hour				
Depth of cut, inches	Classification of material			
	Loose earth	Packed earth	Hard-pan	Pave-ments
18	43	34	27	36
12	36	29	21	30
9	30	24	18	24
6	24	18	12	18

TABLE V.—*Macadam road—Cubic yards crushed rock loose per 100 linear yards of road*

Width, feet	Depth spread, inches						
	3	3½	4	4½	5	6	8
9	25	29. 17	33. 33	37. 50	41. 67	50	66. 67
18	50	58. 33	66. 67	75. 00	83. 33	100	133. 33

Screenings, 0.23 cubic yard for each cubic yard loose of rolled wearing surface

TABLE VI.—*Macadam road—Short tons crushed rock loose per 100 linear yards, 9-foot road*

Weight 1 cubic yard stone, loose	Depth spread, inches						
	3	3½	4	4½	5	6	8
2, 250	28. 13	32. 81	37. 50	42. 19	46. 88	56. 25	75. 00
2, 300	28. 75	33. 54	38. 33	43. 12	47. 92	57. 50	76. 67
2, 350	29. 38	34. 27	39. 17	44. 06	48. 96	58. 75	78. 33
2, 400	30. 00	35. 00	40. 00	45. 00	50. 00	60. 00	80. 00
2, 450	30. 63	35. 73	40. 83	45. 94	51. 04	61. 25	81. 67
2, 500	31. 25	36. 46	41. 67	46. 87	52. 08	62. 50	83. 33
2, 550	31. 88	37. 19	42. 50	47. 81	53. 13	63. 75	85. 00
2, 600	32. 50	37. 92	43. 33	48. 75	54. 17	65. 00	86. 67

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TABLE VII.—*Macadam road—Linear feet 9-foot road for various sizes of loads of rock*

Weight load pounds		Size load	Depth spread, inches					
Granite	Limestone		3	3½	4	4½	6	8
		Cu. yds						
2,800	2,500	1	12.00	10.29	9.00	8.00	6.00	4.50
3,500	3,125	1¼	15.00	12.86	11.25	10.00	7.50	5.63
4,200	3,750	1½	18.00	15.43	13.50	12.00	9.00	6.75
4,900	4,375	1¾	21.00	18.00	15.75	14.00	10.50	7.88
5,600	5,000	2	24.00	20.57	18.00	16.00	12.00	9.00
6,300	5,625	2¼	27.00	23.14	20.25	18.00	13.50	10.13
7,000	6,250	2½	30.00	25.71	22.50	20.00	15.00	11.25
7,700	6,875	2¾	33.00	28.29	24.75	22.00	16.50	12.38
8,400	7,500	3	36.00	30.86	27.00	24.00	18.00	13.50
11,200	10,000	4	48.00	41.14	36.00	32.00	24.00	18.00
14,000	12,500	5	60.00	51.43	45.00	40.00	30.00	22.50

TABLE VIII.—*Macadam road—Quantity of material required for military macadam road*

Loose depth	9-foot road		18-foot road	
	Cubic yards per 100 linear yards	Cubic yards per mile	Cubic yards per 100 linear yards	Cubic yards per mile
1½ inches screenings	8.625	151.80	17.25	303.60
4½ inches	37.500	660.00	75.00	1,320.00
8 inches	66.667	1,173.33	133.33	2,346.67
Total	112.792	1,985.13	225.58	3,970.27
1½ inches screenings	8.625	151.80	17.25	303.60
4½ inches	37.500	660.00	75.00	1,320.00
Total with 2 wearing courses	158.917	2,796.93	317.83	5,593.87

TABLE IX.—*Macadam road—Tonnage of material required for military macadam road*

[Weight, 1 cubic yard stone, loose, 2,000 pounds]

	9-foot road		18-foot road	
	Tons per 100 linear yards	Tons per mile	Tons per 100 linear yards	Tons per mile
1½ inches screenings	11.21	197.34	22.43	394.68
4½ inches	48.75	858.00	97.50	1,716.00
8 inches	86.67	1,525.33	173.33	3,050.67
Total	146.63	2,580.67	293.26	5,161.35
1½ inches screenings	11.21	197.34	22.42	394.68
4½ inches	48.75	858.00	97.50	1,716.00
Total with 2 wearing courses	206.59	3,636.01	413.18	7,272.03

NOTE.—A 9-foot road of 12-inch metal requires 1 cubic yard of excavation per yard of length as trench for metal. Double for 18-foot road; 1 inch metal requires 1/12 excavation, etc.

TABLE X.—*Plank road—Data for a 9-foot road for motor transportation*

Materials	Per 100 yards			Per mile		
	Number	Tonnage	Number of 1½-ton trucks	Number	Tonnage	Number of 1½-ton trucks
Pickets, 6 by 6 inches by 4 feet	40	0.8	0.5	704	14	9
Guard rail, 6 by 6 inches by 10 feet	55	2.8	2	960	48	32
Flooring, 4 by 10 inches by 10 feet	351	19.5	13	6,182	344	230
Stringers, 4 by 10 inches by 10 feet	120	6.7	5	2,112	117.3	78
Sleepers, 4 by 10 inches by 10 feet	75	4.2	3	1,320	73.3	49
Guard rail spikes, 8-inch	220			3,840	1.1	1
Floor spikes, 6-inch	1,404	.3	.2	24,728	5.5	4

NOTE.—For an 18-foot road all quantities are doubled except items 1, 2, and 6, which remain as above. Weights are based on long-leaf yellow pine at 40 pounds per cubic foot. Sleepers are used only when necessary.

TABLE XI.—*Plank road—Data for an 8-foot road for animal transportation (4 by 6 inch stringers)*

Materials	Per 100 yards			Per mile		
	Number	Tonnage	Number of 1½-ton trucks	Number	Tonnage	Number of 1½-ton trucks
Flooring, 2 by 12 inches by 8 feet	294	8	6	5,173	138	92
Stringers, 4 by 6 inches by 12 feet	100	4	3	1,760	71	47
Wire nails, 20d	1,176			20,692	.33	.22

NOTE.—For a 16-foot road double item 1 and increase other items by one-half. Allow ¼ inch between floor plank when dry.

TABLE XII.—*Plank road—Data for an 8-foot road for animal transportation (2 by 12 inch stringers)*

Materials	Per 100 yards			Per mile		
	Number	Tonnage	Number of 1½-ton trucks	Number	Tonnage	Number of 1½-ton trucks
Flooring, 2 by 12 inches by 8 feet	294	8	6	5,173	138	92
Stringers, 2 by 12 inches by 12 feet	50	2	1.33	880	35	24
Nails, 20d	1,176			20,692	.33	.22

NOTE.—For a 16-foot road double all quantities.

TABLE XIII.—*Tread road—Data for tread road for motor transportation*

Materials	Per 100 yards			Per mile		
	Number	Tonnage	Number of 1½-ton trucks	Number	Tonnage	Number of 1½-ton trucks
Flooring, 4 by 10 inches by 10 feet	180	10	7	3,156	175	117
Sleepers, 4 by 10 by 30 inches	120	1.7	1	2,112	30	20
Spikes, 6-inch	540	.12	.08	9,468	2	1.35

NOTE.—Allow ½ inch between ends of floor plank. Boat spikes, 6 inches by ½ inch, driven staggered, one for each plank in each sleeper, in ⅜-inch round holes. In emergency nail with 60d wire nails.

TABLE XIV.—*Corduroy road without stringers—Data for simple 9-foot corduroy road without stringers or guard rail*

Materials	Per 100 yards			Per mile		
	Number	Tonnage	Number of 1½-ton trucks	Number	Tonnage	Number of 1½-ton trucks
Logs, 6 inches mean diameter, 10 feet long	600	28	19	10,560	498	332

NOTE.—Any available material may be used. Calculations are based on white oak at 48 pounds per cubic foot. Timber will generally be cut alongside road and transported by hand or snaking.

TABLE XV.—*Corduroy road with stringers—Data for 9-foot corduroy road laid on stringers*

Materials	Per 100 yards			Per mile		
	Number	Tonnage	Number of 1½-ton trucks	Number	Tonnage	Number of 1½-ton trucks
Stringers, 6 inches mean diameter, 10 feet long	120	10	7	2,112	177	118
Flooring, 6 inches mean diameter, 10 feet long	600	28	19	10,560	498	332
Guard rails, 6 inches mean diameter, 10 feet long	55	2.6	2	960	45	30
Pickets, 6 inches greatest diameter, 4 feet long	40	.6	.33	704	11	7
Guard rail spikes, 10 inches	220			3,840	1.4	1
Floor spikes, 10 inches	2,400	.9	.6	42,240	15.4	10

NOTE.—Any available material may be used. Calculations are based on white oak at 48 pounds per cubic foot. Timber will generally be cut alongside road and transported by hand or snaking. For an 18-foot road, items 1, 2, and 6 are doubled; items 3, 4, and 5 remain as above. Spikes are ½ inch.

41. Loading and spreading earth.—The following values are useful for calculations for earth handling:

Q=1.72 cubic yards loose heavy soil shoveled into carts or wagons per hour per man.

Q=2 cubic yards loose loam shoveled into carts or wagons per hour per man.

Q=2.40 cubic yards loose light soil shoveled into carts or wagons per hour per man.

Q=50 cubic yards place measure moved per hour by elevating grader.

$Q=7.5$ cubic yards loose earth in 6-inch layers spread per man per hour.

$Q=50$ cubic yards loose earth in 6-inch layers spread per grader per hour.

$Q=90$ cubic yards loose earth in 6-inch layers spread per road machine per hour.

42. Transportation of earth or crushed rock.—In making calculations of time for handling earth or crushed rock the quantity of material moved per hour by wheelbarrow, scraper, wagon, or truck may be determined from the following formula:

$$Q=\frac{60}{d+\frac{2l}{r}}\times c.$$

Where Q=number cubic yards, place measure, moved per hour.

l=length haul in feet.

c=capacity vehicle in cubic yards, place measure.

d=total minutes delay—loading, emptying, waiting, etc.

r=rate of vehicle in feet per minute—200 for wheelbarrow or wagon (animal-drawn), 700 for truck.

43. Miscellaneous useful crushed-rock data.

$Q=5$ cubic yards loose rock spread by 2 men in 1 hour when dumped on road.

$Q=5$ cubic yards loose rock spread by 4 men in 1 hour when dumped alongside road; or 4 cubic yards heavy Telford.

$Q=50$ cubic yards loose rock spread by 2 men (driver and helper) with grader.

$Q=1$ cubic yard loose screenings spread by 1 man in 1 hour.

$Q=6.5$ cubic yards loose rock compacted by 1 road roller in 1 hour.

$Q=0.48$ cubic yard Telford base laid by 1 man in 1 hour.

$Q=1.25$ cubic yards loose rock loaded in carts or wagons by 1 man in 1 hour.

$Q=10$ gallons water per square yard surface for water-bound macadam road.

TABLE XVI.—*Gyratory rock crushers*

Size	Dimensions, receiving spider openings		Capacity in tons per hour varying with character of rock		Horsepower for crusher, elevator, and screen	Approximate weight of crusher
	Each about	Both about	Tons	To pass diameter ring		
				Inches		
2	8 ×22	8 × 44	5- 10	2¼	12- 15	10,000
3	8½×24	8½× 48	10- 20	2½	20- 25	15,000
4	9 ×27	9 × 54	15- 30	2½	25- 30	23,500
5	12 ×35½	12 × 71	25- 50	2½	30- 50	32,000
6	12½×37	12½× 74	45- 90	3	40- 60	44,000
7½	14 ×44	14 × 88	90-150	3½	75-125	67,500
8	19 ×60	19 ×120	130-225	4	100-150	100,000
10	25½×72	25½×144	400-600	5	175-250	180,000

TABLE XVII.—*Jaw rock crushers* [1]

Number by which each size of crusher is known	No. 1½	No. 2	No. 2½	No. 3	No. 4
Size of jaw opening for receiving stone, in inches	8×15	9×16	10×20	10½×22	12×28
Product per hour in tons when machine closes to 2 inches	10-15	12-18	15-25	15-30	25-40
Weight in pounds	5,000	7,000	9,250	15,500	27,000
Weight, mounted on 4 wheels, with 12-foot elevator, in pounds	7,500	9,500	12,000	(2)	(2)
Speed, revolutions per minute	275	275	265	265	240
Driving pulleys, diameter and face, inches	30×8	32×9	36×11	38×10	44×12
Horsepower required	12	15	20	25	35
Floor space required, length	5′6″	6′6″	7′6″	7′	8′6″
Floor space required, width	5′	5′1″	5′9″	5′6″	6′
Extreme height of machine	3′5½″	4′3″	5′2½″	4′7″	5′7″
Size of elevator best suited	No. 2	No. 2	No. 2½	No. 3	No. 3
Diameter of screen best suited, in inches	30	30	36	36	42

[1] Reprinted by permission from American Highway Engineers Handbook by Arthur H. Blanchard, published by John Wiley & Sons (Inc.).
[2] Not mounted.

44. Emergency passage of mine craters.—The following gives the relative speed of emergency repairs to mine craters:

Method of repair	Man-hours required
With shovels alone	4×volume in cubic yards.
With shovels and wheelbarrows	2×volume in cubic yards.
With shovels and wagons where distance is not over 200 yards and number of wagons is ¼ number of men	2×volume in cubic yards.
With shovels and scrapers	1×volume in cubic yards.
With standard bridge trestle and bents (trained workmen)	15×diameter in yards.
With timbers (trees in vicinity, trained workmen)	60×diameter in yards.
Detour of corduroy (corduroy available in vicinity)	18×diameter in yards.
Detour of planks	9×diameter in yards.

NOTE.—The volume of a mine crater is

$$V=\frac{\pi D^2 d}{12}.$$

Where V = volume of crater in cubic yards.
$\pi=3.14$
D = distance across top of crater in yards.
d = depth of crater in yards.

SECTION VI

PLANT AND EQUIPMENT

45. Quarry equipment.—*a. Drills.*—Production of rock in quantity for crushing is accomplished by the use of explosives. The selection of the method of drilling is governed by the amount and nature of the work. On small jobs, where but a limited output is required, the drilling is ordinarily done by hand. The drills should be of the best steel and should be kept well sharpened. On large temporary jobs, tripod drills are the most satisfactory. These may be run by either steam or compressed air. When a steam boiler is available, the steam drive is preferred. Either a small portable boiler or a portable compressor driven by a gasoline engine is satisfactory. In large quarries of a permanent character, an air compressor plant with a central power house is the most satisfactory installation. For many jobs, especially when frequent moves are necessary, the light hammer drill, also operated by compressed air or steam, is preferable. Portable gasoline-driven compressors capable of being transported by light trucks are now in common use.

b. Crushing plant.—(1) This consists of the crusher, elevator, screening equipment, and storage bins.

(*a*) *Crushers.*—For large output the stone is crushed by a gyratory crusher; these are also made in small portable sizes. The output of gyratory crushers permanently installed may be as high as 600 tons per hour. These are suitable for installation in the zone of the interior, the communications zone, and in certain situations in the rear areas of the combat zone. For emergency work in the combat zone the most suitable type is the portable jaw crusher, with portable or knock-down bins, elevator and screen, the whole of which may be moved by tractor or truck. These come in several sizes, with output varying from 10 to 40 tons per hour.

(*b*) *Elevators.*—These may be purchased in any practical length and capacity. For portable plants they are made in either the rigid or folding type. The elevator frame is of iron pipe, is strongly cross braced, and carries grooved rollers to support the bucket chains. The buckets are of heavy sheet steel.

(*c*) *Screens.*—As all types of crushers break the stone into a number of different sizes, it is necessary to provide some kind of screen to separate the different sizes as they are used for various purposes on road work. The most satisfactory is the rotary cylindrical screen, which has perforations that permit the stone of different sizes to fall into different bins.

(*d*) *Bins.*—For permanent installations these are usually designed especially for each plant, although manufacturers furnish standard designs. For portable crushers manufacturers furnish portable bins of various designs. One type has three compartments holding 28 tons, another has four compartments holding 28 tons, another has four compartments holding 35 tons; the first weighs about 9,000 pounds, the second 11,000 pounds. Wagons can be loaded by gravity from chutes. The frame is of white oak, the body of hard pine, all braced with iron and steel reinforcement. The bottoms of the bins are lined with steel plates.

(2) *Installations.*—Figure 29 shows elevations of a portable crushing plant with steel pipe frame elevator and screen mounted on a semiportable bin.

(3) *Delivery to crushers.*—Each quarry is provided with the necessary equipment for delivering the large stone to the crushers;

gravity is used to the utmost in efficient layouts. Delivery is various, from that by hand to industrial railway with hand or air dump cars.

46. Earth-grading equipment.—For the loosening and moving of earth in quantity, some or all of the following equipment are indispensable; plow, grader, scraper, and steam shovel.

a. Plows.—Two types of plow are in general use; the rooter, and the road plow with its different modifications for ditching and ditch cleaning.

(1) The rooter is a heavy modification of the ordinary subsoil plow, having a pointed grubber at the bottom. It is used for grubbing roots, shallow breaking of hard ground, and breaking up of macadam or paving when a scarifier is not available. Such a plow is ordinarily drawn by a heavy team of from four to eight horses, while occasional use is made of a light tractor. It is especially useful in very shallow cuts and in loosening the ground ahead of road graders.

(2) Road plows are made in all sizes from 2-horse to 16-horse, and are generally classified as railroad plows. The No. 5, 4-horse, is in most general use. It is used for shallow breaking of hard ground in grading and ditching. Modifications of the road plow have wide spreading mold boards which are used for moving loosened soil out of ditches toward the center of the road.

b. Graders.—(1) *Blade.*—Blade graders for loosening, moving, and shaping earth serve a variety of useful purposes in road construction and repair. They come in sizes and weights adaptable to different conditions, the motive power ranging from a 2-horse team to a heavy tractor. In road construction their greatest use is for smoothing the surface and for digging side ditches and forcing the earth toward the center to form a crown. In repair work they are useful in cleaning ditches, recrowning and smoothing the surface, and in filling ruts. For repairs they can be depended upon to accomplish more on rough surfaces than is possible when using a drag, but in most cases it is advisable to follow the machine with a drag. The drag should be used solely when the work is light enough to be accomplished by it. The great variety of uses to which a blade grader lends itself makes it a practical necessity for road construction and maintenance. Often two or three light machines are used in tandem behind a heavy tractor for completing the ditch and grading of one side of a road at one passage.

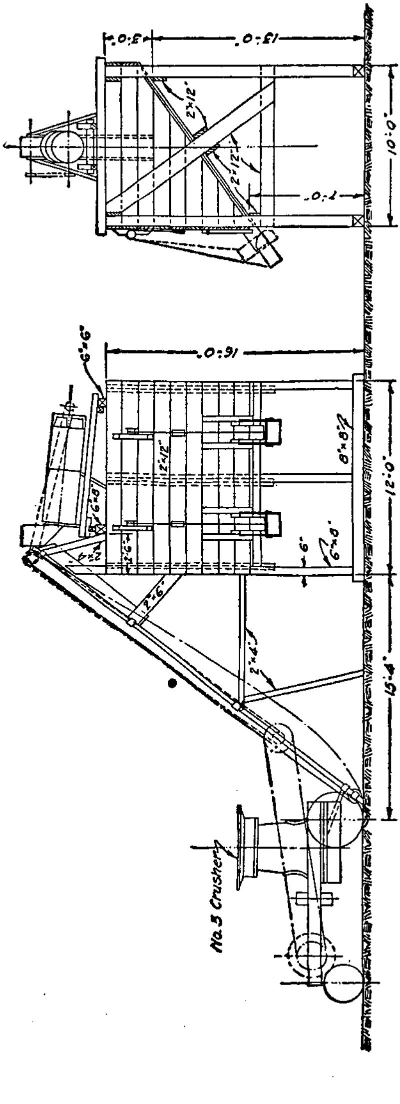

FIGURE 29.—Semiportable crushing plant. (Courtesy Austin Manufacturing Co.)

(2) *Elevating.*—The elevating grader is tractor-drawn and equipped with a plow, which turns the furrow directly on to an endless belt conveyor. This carries the earth upward and outward from the machine until it is thrown from the belt on the side opposite the plow. The earth may be loaded into wagons or spoiled, depending upon conditions. A machine handled by one man has loaded into wagons as much as 100 cubic yards of earth per hour and spoiled over twice as much. This grader is used to good advantage in construction on the following classes of roads:

(*a*) Roads practically level where the new grade line is parallel to the profile on the old road, there being only a few knolls to be removed.

(*b*) Roads on which there are a succession of knolls and consequently a succession of cuts and fills, most of which do not exceed about 2 feet in depth.

(*c*) Roads where extensive grade reduction work must be done.

c. Scrapers.—(1) *Drag or slip.*—Drag or slip scrapers are suitable for moving earth if the haul does nor exceed 150 feet. The capacity varies from 3 to 12 cubic feet. They are well suited to small jobs, as the driver may also load and dump. However, on grading operations it is frequently economical to provide additional men at the rate of one loader and one dumper and spreader for four scrapers. The material must usually be loosened with a plow.

(2) *Wheel.*—Wheel scrapers are used for general earth moving work where the haul is from 150 to 600 feet. For moving earth greater distances than 600 feet wagons are generally more economical even when loaded by hand. The capacity of scraper varies from 5 to 18 cubic feet. The larger size is preferable on heavy work. A snatch team is usually employed with the medium-sized scraper and always with the larger-sized scraper at the rate of one snatch team per four scrapers. One loader and one dumper and spreader are needed for each four small or medium-sized scrapers. Two loaders and one dumper and spreader are needed for each four large sized scrapers. The material must usually be loosened with a plow. The common practice is to plow two furrows on one side of the cut, then wheel them out while two furrows are being plowed at another place in the cut. It generally requires one scraper to 100 feet of haul to keep a crew in continuous operation.

(3) *Fresno.*—The Fresno scraper is widely used on the Pacific coast, and to a lesser degree elsewhere, for the same purposes as the slip scraper. It is more efficient than the latter and is suitable for hauls up to 500 feet. The Fresno is dragged through plowed ground by team or tractor until it fills with earth. In downhill operation it pushes a large amount of additional material with it. At the back of the frame is a long handle which acts as a lever for dumping. With one hand the driver lifts this handle, tipping the pan slightly. The team or tractor, attached to pull rods, completes the operation, pulling the pan over until it rests on two runners; these lift the pan clear of the ground and permit the load to be discharged. The back and sides are riveted to an angle which is given the proper curve.

d. Steam shovels.—Where heavy grading is being done, so that an outfit can be worked without frequent moves, the steam shovel is suitable. For road work the traction type may be used in conjunction with dump trucks or wagons.

47. Rock and earth transportation.—In the forward areas, in emergencies, materials in small quantities may be transported in packs by animal, by wheelbarrow, sled, containers mounted on runners, basket, box, boxes fitted with handles, sandbags, and tin containers. In construction and repair work, earth and stone are ordinarily transported by dump trucks, dump wagons, and dump carts. Tractors may be utilized to haul dump wagons.

a. Dump trucks.—Dump truck companies are provided for road work in the theater of operations. The trucks have a capacity of from 1½ to 2 tons and are suitable for hard conditions of military service in areas where only limited loads may be hauled. Commercial trucks up to 5 tons' capacity are in common use and will be utilized in campaign where conditions warrant.

b. Dump wagons.—(1) *Escort or farm wagons.*—An ordinary escort or farm wagon may be rigged up for the transportation of crushed stone, gravel, earth, or similar material. The most commonly used type consists of a wagon with a box made of two heavy boards for the sides and a number of narrow boards for the bottom. Such a wagon is dumped by lifting up one of the sideboards and then tipping the narrow bottom boards on edge, one at a time. While giving good service, and very useful on a small job in an emergency, this type of wagon is not as satisfactory as a commercial dump wagon or cart.

(2) *Bottom dump wagons.*—There are a great many types of commercial bottom dump wagons on the market. These are very satisfactory for hauling earth on grade reduction work if the haul is to exceed 600 feet, and are also used in connection with an elevating grader on earth road construction. They may be had in capacities from 1 cubic yard to 5 cubic yards as desired, but the 1½ or 2 yard sizes are best adapted for road construction. The bottom dump wagon is commonly used for hauling broken stone, sand, gravel, and similar material.

(3) *End dump wagons.*—These are useful to dump into hoppers, barges, railroad cars, and sometimes to facilitate the spreading of material. They are too heavy and high for use in ordinary earthwork construction.

c. Dump carts.—These are ordinarily built quite heavy and substantial, with wide tires and an automatic dumping hopper that deposits the load at the rear. They are for one horse, and on account of turning in short space and ease of backing, are serviceable in cut and fill work, and for making general repairs where considerable amounts of material must be hauled. They are especially valuable on military road work executed by the forward echelons of engineers.

48. Road rollers.—In road construction, rollers are used for compacting the foundation and the metal crust. The object of rolling is to press the material closer together in order to reduce the voids. Rollers make satisfactory tractors, especially for hauling heavy loads over newly constructed work. The motive power distinguishes three distinct varieties of rollers—animal-drawn, gasoline, and steam. The choice between the two varieties of power rollers is usually made to suit the local conditions with regard to fuel and water. These are generally used in road work, although on certain classes of light work the animal-drawn is also used. Power-driven rollers are of two types, known respectively as macadam and tandem. The macadam or 3-wheeled roller is designed for compacting embankments and for rolling the foundations of roads and their crust. The weight may be from 8 to 20 tons, but for all-around work the 10-ton size is most suitable. The tandem roller has two divided rolls so arranged that they cover the same path when the machine is in operation. The steering roll is smaller in diameter than the driving roll, but the weight is so distributed that both give about the same compression to the surface. The tandem roller is built in sizes weighing from 4 to 16 tons. A light roller may be improvised by filling a cylindrical container, such as a gasoline drum, with water, or a drum or a pipe with concrete. A concrete roller can be improvised also by using wooden forms.

49. **Scarifiers.**—The difficulties of breaking up packed surface material or paving are largely overcome by the correct use of scarifiers. These are heavy machines, resembling a narrow but exceedingly strong harrow; the teeth are set with a forward slant so that they will enter and divide the paving. Their use is limited to the repair of roads and streets. They are especially adapted for renovation where the surfacing material only is to be disturbed and where the subgrade is to be left intact. On account of the heavy work to which they are subjected they must be strongly built. They are ordinarily drawn by tractors or are fitted to road rollers.

50. **Snow-removal equipment.**—The following equipment is in general use for the removal of snow from roads:

a. Road machines.

b. Trucks equipped with straight blades.

c. Tractors equipped with straight blades.

d. Tractors equipped with V-plows.

e. Trucks equipped with V-plows.

f. Rotary snowplows.

g. Improvised substitutes, such as animal-drawn plows, tanks, improvised plows operated by tanks, etc.

CHAPTER 2

BRIDGES

Section I

GENERAL PRINCIPLES, CLASSIFICATION, AND TYPES

51. Classification.—*a.* Military bridges may be classified as to type, as floating bridges and fixed bridges.

(1) *Floating bridges* include light footbridges using floats consisting of kapok pillows or canvas-covered frames, ponton bridges, and bridges supported on barges, rafts, or other form of floating support.

(2) The *fixed bridges* commonly constructed in military operations include footbridges on light trestles, simple stringer bridges, timber trestles, pile trestles, spar bridges, trusses, and suspension bridges.

b. Military bridges are also classified according to capacity as foot, light, and heavy bridges.

(1) *Footbridges* are designed to pass infantry soldiers fully equipped in single file.

(2) *Light bridges* are designed to carry the loads of an infantry division.

(3) *Heavy bridges* are designed to carry the heaviest military loads.

52. Types.—The type of bridge to be constructed in a given case depends upon tactical considerations such as the time available for construction, the position and strength of the enemy, and the loads to be carried, and upon certain technical features such as the length of span, the nature of the footings, the depth of water, the velocity of the current, the profile of the gap, and the materials and construction equipment available.

a. Floating bridges.—Floating bridges are adapted to tactical operations where surprise as to location and speed of construction are essential.

b. Fixed bridges.—Fixed bridges are used when time is available for their construction. Where floating bridges have been installed they are replaced by fixed bridges as soon as practicable, releasing the floating equipage for use elsewhere. Heavy fixed bridges are always used for main highways. On secondary highways time and materials may be saved by using light bridges when the characteristics of pavement, dimensions, grades, and location of the highways indicate that they will not be called upon to pass the heaviest military loads.

c. Supports.—The choice of supports depends upon the character of the footings. Trestle bents or piers being simple to construct are used wherever practicable. Pile bents or piers are used in soft bottom. Crib piers are easy to erect and are adapted to nearly all sites, but require much timber. New masonry piers are rarely used for military bridging operations, but use is often made of the remaining portions of those which have been partially demolished.

d. Span.—Simple stringers of either timber or steel are used for short spans. Trusses and girders are used for long spans where opportunity exists to obtain the fabricated parts.

e. Suspension bridges.—Suspension bridges and cable ways are employed to span deep ravines or streams in situations where the construction of piers is impracticable.

f. Portable bridges.—Portable bridges made of demountable steel trusses or the trestle sections of ponton-bridge equipage may be used in lieu of other types when available.

53. Bridge loads.—Information as to the character of the military loads likely to be imposed upon the bridges is necessary as a basis both for the design of new bridges and for determining whether an existing bridge can pass a given vehicle. Table XVIII shows the dimensions and weights of some typical military bridge loads.

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TABLE XVIII.—*Typical bridge loads*

Kind of load	Total load (vehicle plus cargo)	Axle loads: Front, Empty	Axle loads: Front, Loaded	Axle loads: Rear, Empty	Axle loads: Rear, Loaded	Distance between axles (wheel base) designated by "l" in formulas	Width (center to center of wheels) (tread)	
	Pounds					*Inches*	*Inches*	
Men, in single file	140 per lin. ft.							
Infantry, column of twos	280 per lin. ft.							
Cavalry, column of twos	392 per lin. ft.							
Pack train	250 per lin. ft.							
Escort wagon, 4-mule	5,000		1,780		3,220	71¼	61½	
Kitchen, rolling	4,800		1,900		2,900	105	63	
Car, motor, light, open	2,953	771	886	1,432	2,067	103½	56	
Car, motor, medium, open	3,300	600	825	1,800	2,475	114	56	
Car, motor, heavy, open	5,540	1,070	1,385	3,210	4,155	132	56	
Car, motor, light, closed	3,169	847	951	1,572	2,218	103½	56	
Car, motor, medium, closed	3,600	600	825	1,800	2,475	114	56	
Car, motor, heavy, closed	5,720	1,167	1,430	3,503	4,290	132	56	
Truck, ½-ton	3,950	625	937	1,875	2,813	114	56	
Truck, ¾-ton	5,950	1,112	1,490	3,338	4,470	132	56	
Truck, 1-ton, reconnaissance	7,000	1,250	1,750	3,750	5,250	140	56	
Truck, 1½-2-ton	9,000	1,475	2,250	4,425	6,750	145½	56	
							Front	Rear
Truck, 3-5-ton (C1 "B")	20,700	3,120	6,210	7,280	14,490	160½	64½	67
Truck, 5-ton	22,000	3,300	6,600	7,700	15,400	168	68½	71½
Truck, machine shop	22,000	4,950	6,600	11,550	15,400	168	68½	71½
Truck, water purification	16,000		5,500		10,500	160½	64½	67

Truck, Cadillac searchlight, 60-inch mobile	7, 030	1, 070	1, 557	3, 210	5, 273	145		56
Truck, searchlight, new model	9, 860		3, 440		6, 420	150		56
Gun, 37-mm	1, 231		871		360	61		33
Gun, 75-mm	4, 586		2, 043		2, 543	150		60
Gun, 155-mm	29, 920		12, 160		17, 900	177		88
Howitzer, 105-mm	5, 227		1, 622		3, 605	189		60
						Ground contact	Tread	Width of shoe
Tractor, 5-ton	10, 000					91	44	11
Tractor, 10-ton	22, 000					80	72	15
Tank, light	14, 500					80	55⅛	13⅜
Tank, medium	46, 000					120	78	18
Tank, heavy, Mk. VIII	86, 000					111½	69½	26½

54. Factor of safety.—To guard against undiscernible defects in the structural material and to provide against increased loads due to unforeseen circumstances and minor errors in design and construction, the ultimate strength of a material is never used in design. This stress is divided by a factor called the factor of safety, and the result is used as the working stress for design. The factor of safety usually is from 4 to 6. In steel and similar homogeneous material the factor of safety is usually 4. For certain structures, such as piles, where the unknown elements are numerous, the factor of safety is usually increased to 6, or even more.

55. Materials.—*a. Wood.*—In selecting sizes of wooden parts for bridges, care should be taken to call for commercial sizes only. The following sizes are common commercial dimensions of lumber:

Spruce

2 x 3	2 x 4	2 x 5	2 x 6	2 x 7	2 x 8	2 x 10	2 x 12
3 x 4	3 x 6	3 x 8	3 x 10	3 x 12			
4 x 4	4 x 6	4 x 8	4 x 10	4 x 12			
6 x 6	6 x 8	6 x 10	6 x 12				
8 x 8	8 x 10	8 x 12					

Yellow Pine

Sizes about the same as for spruce; also

2 x 14	2 x 16
3 x 14	3 x 16
4 x 14	4 x 16
6 x 14	6 x 16
8 x 14	8 x 16
10 x 14	10 x 16
12 x 14	12 x 16
14 x 14	14 x 16
	16 x 16

12 feet to 22 feet are ordinary lengths.
23 feet to 26 feet are less common.
27 feet to 32 feet are obtained with difficulty.

Lengths above 10 feet come ordinarily in size intervals of 2 feet; that is, 12, 14, 16, etc. Anything over 20 feet is considered special. Above 6 inches, sizes of timbers of square cross sections are more apt to be found than others in commercial stocks, and 12 by 12 inches is about the largest. Larger sizes are usually considered as special.

b. Steel.—Steel I beams are used for stringers. In selecting I beams, the standard sections should be called for. The properties of such beams are shown in Table XIX.

TABLE XIX.—*Properties of standard* I-*beams*

Depth of beam	Pounds per foot	Width of flange	Section modulus I/c	Depth of beam	Pounds per foot	Width of flange	Section modulus I/c
24	100.00	7.254	198.4	12	35.00	5.086	38.0
	95.00	7.192	192.5		31.50	5.000	36.0
	90.00	7.131	186.6				
	85.00	7.070	180.7	10	40.00	5.099	31.7
	80.00	7.000	174.0		35.00	4.952	29.3
					30.00	4.805	26.8
20	100.00	7.284	165.6		25.00	4.660	24.4
	95.00	7.210	160.7				
	90.00	7.137	155.8	9	35.00	4.772	24.8
	85.00	7.063	150.9		30.00	4.609	22.6
	80.00	7.000	146.7		25.00	4.446	20.4
					21.00	4.330	18.9
20	75.00	6.399	126.9				
	70.00	6.325	122.0	8	25.50	4.271	17.1
	65.00	6.250	117.0		23.00	4.179	16.1
					20.50	4.087	15.1
18	70.00	6.259	102.4		18.00	4.000	14.2
	65.00	6.177	97.9				
	60.00	6.095	93.5	7	20.00	3.868	12.1
	55.00	6.000	88.4		17.50	3.763	11.2
					15.00	3.660	10.4
15	100.00	6.774	120.1				
	95.00	6.675	116.4	6	17.25	3.575	8.7
	90.00	6.577	112.7		14.75	3.452	8.0
	85.00	6.479	109.0		12.25	3.330	7.3
	80.00	6.400	106.1				
				5	14.75	3.294	6.1
15	75.00	6.292	92.2		12.25	3.147	5.4
	70.00	6.194	88.5		9.75	3.000	4.8
	65.00	6.096	84.8				
	60.00	6.000	81.2	4	10.50	2.880	3.6
					9.50	2.807	3.4
15	55.00	5.746	68.1		8.50	2.733	3.2
	50.00	5.648	64.5		7.50	2.660	3.0
	45.00	5.550	60.8				
	42.00	5.500	58.9	3	7.50	2.521	1.9
					6.50	2.423	1.8
12	55.00	5.612	53.5		5.50	2.330	1.7
	50.00	5.489	50.6				
	45.00	5.366	47.6				
	40.00	5.250	44.8				

56. Dimensions.—*a. Width of roadway.*—Economy of materials requires that the width of roadway be no greater than that required to pass the loads. Infantry soldiers in single file require a walkway with a minimum width of 18 inches. Machine-gun carts and 37-mm. gun carts require a minimum width of 4½ feet. These figures may be used in the design of very light assault bridges. For all other bridges a standard has been adopted of 10 feet clear width between curbs for a single roadway, and 18 feet for a double roadway.

b. Headroom.—The headroom for military bridges should be not less than 14 feet. This will permit the passage of general traffic, including trucks.

c. Waterway.—The clearance beneath the bridge depends upon the kind of river transportation which is permitted to use the stream under the existing military situation. It must be remembered that water-borne transportation may have important military uses. Provision is made in floating bridges for making a draw of the required width to permit river traffic to pass.

57. Flooring.—Floor planks must be 11 feet over-all length as their effective length is reduced to 10 feet by the two 6-inch curbs which rest upon their outer ends. Extra long planks may be inserted at regular intervals to provide supports for the handrail. Floor planks should be of hardwood or of the heavier pines. Although not required by design, the cutting action of heavy tired vehicles makes a flooring of 4 inches in thickness desirable. However, 3-inch flooring may be used. If the floor planks show a tendency to split or the spikes to bend in spiking flooring to the stringers, it may be necessary to bore holes, properly spaced, in the planks. One spike per plank per stringer should be provided, staggering the spikes as shown in Figure 30, if material and time permit. Holes in planks should be $\frac{1}{16}$ inch smaller in diameter than the spikes. The curbs are preferably 6 by 6 inch timbers, although 4 by 6 inch may be used. They are bolted to the outer edge of the flooring to prevent vehicles from going off the bridge, and are fastened to the floor planks with $\frac{3}{4}$-inch bolts spaced three feet center to center, with washers on both ends of the bolts. The handrail is desirable, but not essential. It may be added after the bridge is in use. It should be 3 feet high.

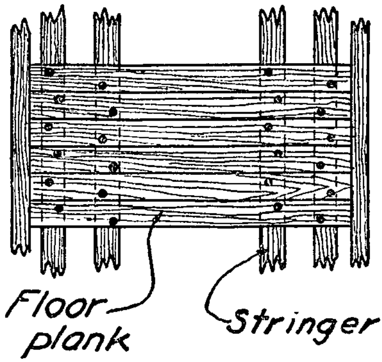


FIGURE 30.—Spiking of flooring

58. Stringer design.—*a. Theory.*—The stringers may be considered as simple beams supported at both ends. Equilibrium requires that the bending moment of the forces applied to the beam be balanced by the resisting moment of the internal forces acting in the fibers of the material of the beam. This condition is expressed by the formula:

$$M = s\frac{I}{y}$$

Where M = the bending moment of the applied forces.
s = the stress in the material.
I = the moment of inertia of the cross section of the beam.
y = the distance of the extreme fiber from the neutral axis of the beam.

b. Section modulus.—The expression $\frac{I}{y}$ is called the section modulus and depends solely on the shape and size (not on the material) of the cross section of the beam. The section modulus for a rectangular beam is $\frac{bd^2}{6}$, where b and d are the breadth and depth of the cross section in inches. The section modulus for a round beam is approximately $\frac{d3}{10}$, where d is the diameter of the cross section in inches. The section modulus for I-beams of various sizes may be obtained from Table XIX.

c. Applied forces.—The forces applied to a beam include the dead weight of the flooring and of the beam itself, the moving or live loads on the span and the reactions or upward thrust of the supports. All these forces must be considered in determining the stress in the beam.

d. Bending moment.—A moment is a turning force and at any section along a beam is measured mathematically by the intensity of the force multiplied by its distance from that section. The bending moment at any section of a beam equals the algebraic sum of the moments of all the forces on the left of that section, moments tending to turn the beam in a clockwise direction being taken as positive, and those in a counterclockwise direction as negative.

e. Dead load.—For short span bridges (say, up to 16 feet) it is usually sufficient to add an extra stringer to take care of the dead load. For longer spans the bending moment of the dead load should be separately computed and added to the bending moment of the live or moving load. The dead load is a uniformly distributed load, giving for the maximum bending moment at the center of the span:

$$M=\frac{WL}{8}$$

Where M=the maximum bending moment in inch-pounds.
W=the total dead load in pounds. It includes the weight of the flooring and of the stringers themselves.
L=the span in inches.

The dead weight of timber spans for a 10-foot roadway is approximately 325 pounds per lineal foot of span.

f. Live loads.—In making computations of the stresses caused by live loads, the live loads should be considered when so placed that they produce the maximum bending moment. There are two principal kinds of live loads to consider: The wheeled load, exemplified by the truck or the gun; and the track-laying load, exemplified by the tank or the tractor. The former represents one or more concentrated axle loads, the latter a uniformly distributed load. In designing stringers for truck loads for spans of less than the wheel base of the truck, the maximum bending moment occurs at the center of the span when the heavier axle load is at the center of the span. The other axle is then off the span entirely. The maximum bending moment for this case is given by the formula:

$$M=\frac{WL}{4}$$

Where M=the maximum bending moment in inch-pounds.
W=the axle load in pounds.
L=the span in inches.

For spans greater than the wheel base of the truck the maximum bending moment when both axles are on the span occurs at the heavier axle load when the distance from the center of gravity of the load to the point of heaviest application is bisected by the center of the span. However, this moment may not be so great as the moment of only one of the axle loads at the center. The position of the truck for absolute maximum bending moment must therefore be determined by trial. The maximum bending moment produced by a tank or tractor load, which is long enough entirely to cover the span, occurs at the center of the span when the load completely covers the span, and is given by the formula:

$$M=\frac{WL^2}{8l}$$

Where M=the maximum bending moment in inch-pounds.
W=the total weight of tank or tractor in pounds.
L=the span in inches.
l=the length of the ground contact of the load in inches.

When the tank or tractor load is not long enough to cover the entire span, the maximum bending moment can, with sufficient accuracy, be found from the formula:

$$M=\frac{WL}{4}-\frac{W}{8}$$

Where M, W, L, and l have the same meanings as before.

g. Formula for selecting stringers.—From the foregoing theory are derived the following formulas for selecting stringers. The nomenclature used in the formulas is as follows:

M=the maximum bending moment in inch-pounds.
N=the total number of stringers required in the span.
s=the allowable fiber stress of the material in pounds per square inch.
b=the breadth of a stringer in inches.
d=the depth of a rectangular stringer or the diameter of a round stringer in inches.
S=the section modulus of an I beam as given in Table XIX.

(1) To compute the number of rectangular wooden stringers required to carry a given load, breadth and depth of stringers given:

$$N=\frac{6M}{sbd^2}$$

(2) To compute the number of round timber stringers required to carry a given load, diameter of stringers being given:

$$N=\frac{10M}{sd^3}$$

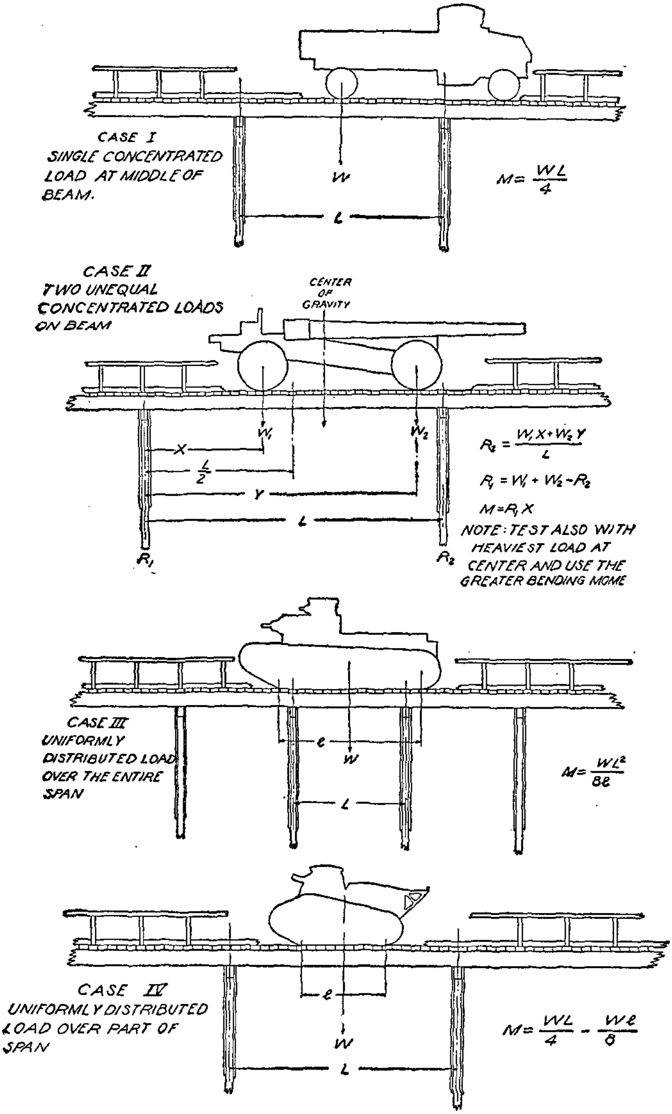


FIGURE 31.—Maximum bending moment in stringers under typical loadings

(3) To compute the number of I beams required to carry a given load, size of I beams being given:

$$N=\frac{M}{sS}$$

(4) To compute the maximum bending moment which a single rectangular wooden stringer of given breadth and depth can carry:

$$M=\frac{sbd^2}{6}$$

(5) To compute the maximum bending moment which a single round timber of given diameter can carry:

$$M=\frac{sd^3}{10}$$

(6) To compute the maximum bending moment which a single I beam can carry:

$$M=sS$$

(7) It should be noted that for a given weight a concentrated axle load at the center of the beam produces the greatest stress in the beam. If the same weight be divided among two or three axles, the stress in the beam is less, regardless of the position of these loads. A uniformly distributed load extending over the entire span stresses a beam only one-half as much as the same weight concentrated at the center. It may therefore be taken as a safe rule that a beam which is strong enough to carry a given weight concentrated at the center of the beam is also strong enough to carry the same weight in any position and however it may be distributed along the beam.

h. Load carried by any one stringer.—If the stringers are placed directly under the wheel tracks of the load and the floor planks are sufficiently stiff to distribute the load among the stringers, each stringer will carry about its proportional share of the load. A safe working assumption in this case is that any one stringer may have to carry 25 per cent more than its pro rata share, but if the stringers are evenly spaced on cap, as is frequently the case, or if the floor planks are not sufficiently stiff to distribute the load equally among the stringers, any one stringer may have to carry more than its proportional share of the load. A fair working assumption in this case is that any one stringer may have to carry one-third of the total bending stress in the span. After the size and number of stringers have been determined by means of the formulas given, a test calculation should be made to see if any one stringer is sufficiently strong under these assumptions.

i. Allowable working stresses.—The allowable working fiber stress, s, depends upon the material used and equals the ultimate strength of the material, modified by a factor of safety. For timber the allowable stress in bending is generally taken as 800 pounds per square inch for soft wood to 1,200 pounds for the best hard wood. The working stresses for various woods are given in Table XX. For steel the allowable fiber stress in bending is 16,000 pounds per square inch.

j. Use of diagrams for selecting stringers.—The foregoing formulas have been worked out graphically in Figure 32. These diagrams may be used in the selection of stringers for any given span and bending moment. It should be noted that in order to use these diagrams the bending moment must be expressed in foot-pounds. Foot-pounds equal inch-pounds divided by 12.

59. Caps.—*a. Theory.*—The size of the cap must be great enough to provide sufficient bearing area for both the stringers above and the posts below so that neither the cap nor the stringers will fail by crushing. Ordinarily, the posts are placed directly or nearly under the stringers, but if they are not so placed, the cap may act as a beam and must be investigated for strength against bending in the manner described above for stringers. To test for strength against crushing the formula is

$$A=\frac{P}{S}$$

Where P=the load in pounds.
A=the area in square inches over which the load is distributed.
S=the allowable unit crushing stress of the material in pounds per square inch. (See Table XX.)

b. Live loads.—(1) The maximum live load on the cap produced by a truck or gun load occurs when the heaviest axle load is directly over the cap. For this case,

$$\text{Maximum live load on cap in pounds}=W_1+\frac{W_2(L-l)}{L}$$

Where W_1=axle load over the cap in pounds.
W_2=the other axle load in pounds.
L=span in inches.
l=wheel base of vehicle in inches.

(2) The maximum live load on the cap produced by a tank load occurs when the tank is directly above the cap. For this case,

$$\text{Maximum live load on cap in pounds} = W - \frac{Wl}{4L}$$

Where W = the total load in pounds.
L = the span in inches.
l = the length of ground contact of the tank or tractor.

(3) It should be noted that for a given total load the maximum load on the cap results from concentrating that load directly over the cap. The effect of dividing the total load among several axles or of distributing it as a tank or tractor does is to decrease the maximum load on the cap regardless of the position of these loads.

c. Dead load.—The dead load on the cap is equal to one-half of the dead weight of the spans resting upon it.

TABLE XX.—*Simple timber construction, working unit stresses*

[Safe allowable working unit stresses in pounds per square inch]

Kind of timber	Tension		Compression			Transverse		Shearing	
			With grain						
	With grain	Across grain	End bearing	Columns under 15 diameters	Across grain	Extreme fiber stress	Modulus of elasticity, E/2	With grain	Across grain
Factor of safety	Seven.	Ten.	Five.	Five.	Four.	Six.	Two.	Four.	Four.
White oak	1,700	200	1,400	1,000	500	1,200	750,000	200	1,000
White pine	1,000	50	1,100	800	200	700	500,000	100	500
Southern long-leaf pine	1,700	60	1,400	1,000	350	1,200	750,000	150	1,250
Douglas fir	1,200	60	1,200	900	200	800	750,000	130	1,250
Short-leaf yellow pine	1,200	50	1,100	800	250	1,000	600,000	100	1,000
Red pine (Norway pine)	1,200	50	1,000	750	200	800	565,000	100	1,000
Spruce and eastern fir	1,200	50	1,200	900	200	700	600,000	100	750
Hemlock	900	50	1,100	800	150	600	450,000	100	600
Cypress	900	50	1,000	750	200	800	450,000	100	600
Cedar	1,000	50	1,100	750	200	700	350,000	100	400
Chestnut	900	50	1,100	800	250	800	500,000	150	500
California redwood	1,000	50	1,100	800	150	750	350,000	100	500
California spruce	1,000	50	1,100	800	150	800	600,000	100	500

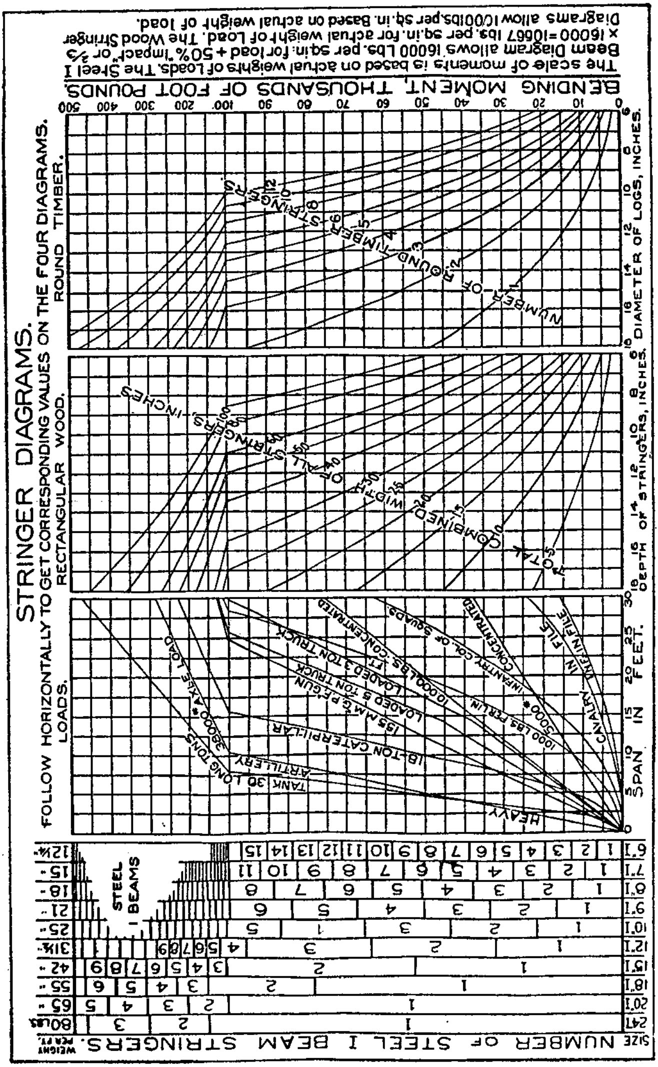


FIGURE 32.—Diagram for selecting stringers

TABLE XXI.—*Allowable working stresses, steel and iron*

Material	Tension per square inch	Compression per square inch	Shear per square inch
	Pounds	*Pounds*	*Pounds*
Structural steel	16,000	16,000	10,000
Average wrought iron	12,000	11,000	9,000
Cast iron	4,000	16,000	3,000

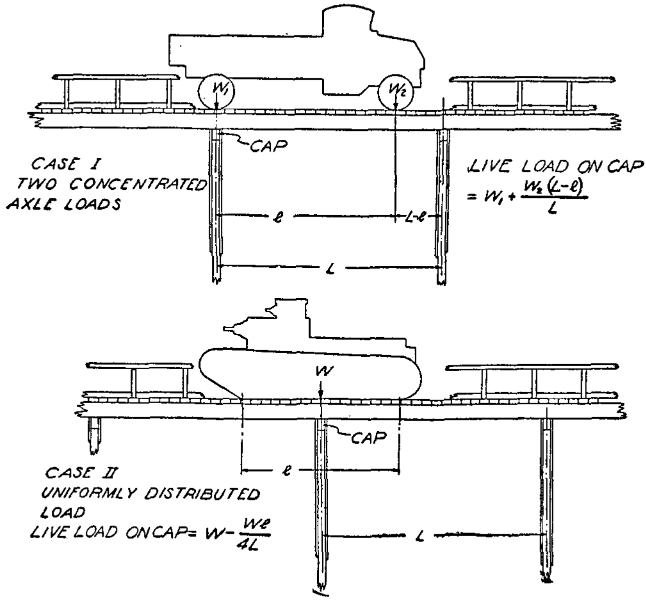


FIGURE 33.—Maximum live load on supports under typical loadings

60. Posts.—*a. Theory.*—The posts are columns and are subjected to longitudinal stresses. The following formula for rectangular wooden columns is used in trestle-bridge design:

$$S_1 = S\left(1 - \frac{L}{60d}\right)$$

Where S_1=the safe unit working stress for columns in pounds per square inch.

S=the safe unit end bearing stress in pounds per square inch, compression with the grain, Table XX.

L=unsupported length of column in inches.

d=least side of column in inches.

Multiply the cross-sectional area of the column by the value found for S_1 to find the total load-bearing capacity of the column. The posts must be capable of carrying the load up to a maximum height. In the single trestle bent support, 24 feet has been found to be the practical maximum height. Above this height, double-story trestles or trestle piers should be used. It should be noted that the necessary size of the posts may depend upon the requirement that their ends have sufficient area of bearing on the caps or sills, so that these will not fail by crushing.

b. Load.—The maximum load on a post consists of its share of the total maximum load on the cap as determined by the methods described in the previous paragraph. Judgment must be used to determine what proportion of the load may possibly come on the post. Where four posts are used and the stringers are so placed on the cap as to fall as nearly as possible under the wheel loads of traffic, it is usually safe to assume that one-third of the total load on the cap may be transmitted to any one of the posts.

Example: What size posts are necessary for a bridge of 20-foot span to pass the medium tank? Unsupported length of posts, 10 feet; 4 posts in the bent.

Answer: Maximum end shear $=46{,}000-\frac{46{,}000\times 120}{4\times 20\times 12}$ =40, 250

Dead load ------------------------------ = 4, 500

Total load on the cap -------------- =44, 750

Assuming that one-third of this total may have to be carried by a single post, the load on the post equals 14,916 pounds. Taking the crushing strength of the material of the cap as 300 pounds per square inch, the required area of bearing on the cap is therefore:

$$\frac{14916}{300}=49.7 \text{ square inches}$$

An 8 by 8 inch post will therefore give ample bearing on the cap or on the sill. Test this size for strength as a column, using the formula:

$$S_1=S\left(1-\frac{L}{60d}\right)$$

Where $S=1{,}200$, from Table XXII.
$L=10$ feet$=120$ inches.
$d=8$ inches.

Substituting these values in the formula:

$$S_1=1{,}200\left(l-\frac{120}{60\times 8}\right)=900 \text{ pounds per square inch}$$

The total bearing power as a column equals $900\times8\times8=57{,}600$ pounds. As this is greater than the maximum load on the column, the column is safe.

TABLE XXII.—*Safe loads, square posts, and for various values of* $\frac{L}{d}$

$S_1=S\left(1-\frac{L}{60d}\right)$ S is assumed to be 1,200

Size	Length	$\frac{L}{d}$	Safe unit stress	Safe load for post
Inches	*Feet*		*Pounds per square inch*	
4 by 4	2	6	1,080	17,280
4 by 4	4	12	960	15,360
4 by 4	6	18	840	13,440
4 by 4	8	24	720	11,520
4 by 4	10	30	600	9,600
6 by 6	4	8	1,044	37,584
6 by 6	6	12	960	34,560
6 by 6	8	16	879	31,644
6 by 6	10	20	800	28,800
6 by 6	12	24	720	25,920
6 by 6	14	28	639	23,004
6 by 6	16	32	559	20,124
8 by 8	6	9	1,020	65,280
8 by 8	8	12	960	61,440
8 by 8	10	15	900	57,600
8 by 8	12	18	840	53,760
8 by 8	14	21	779	49,856
8 by 8	16	24	720	46,080
8 by 8	18	27	659	42,176
8 by 8	20	30	600	38,400
8 by 8	22	33	540	34,560
8 by 8	24	36	480	30,720

61. Piles.—*a. Theory.*—A pile may derive its load-supporting power from the fact that its lower end rests upon a hard stratum or from surface friction all along its embedded length. In the former case the pile is designed as a column. In the latter case the safe load is determined either by loading test piles or by the following formulas:

For piles driven by drop hammer: $P=\frac{2wh}{s+1}$

For piles driven by steam hammer: $P=\frac{2wh}{s+0.1}$

Where P=safe load in pounds. w=weight of hammer in pounds. h=height of fall in feet. s=average penetration in inches under several successive blows of the hammer. The penetration may easily be measured by holding a pencil point against the side of the pile during driving and observing the length of mark made as the pile sinks with the blow of the hammer.

b. Loads.—The maximum load to be carried by a pile is determined in the manner described above as in the case of posts.

c. Example.—Under the last three blows of a steam hammer a pile penetrates 0.8 inch, 0.6 inch, 0.4 inch, respectively. The steam hammer weighs 2,900 pounds and has a height of fall of 1½ feet. Compute the bearing value of the pile.

$$\text{Safe load}=P=\frac{2wh}{s+0.1}$$

$$\text{Average penetration}=\frac{.8+.6+.4}{3}=0.6 \text{ inch}$$

$$P=\frac{2\ (2{,}900)\ (1.5)}{(.6+0.1)}=12{,}429 \text{ pounds (safe bearing value)}$$

The size of the piles should be great enough to provide a sufficient bearing area on the cap so that the latter will not fail by crushing.

TABLE XXIII.—*Bearing power of piles due to penetration in different soils*

For pile of 1 foot mean diameter		
Character of soil	Penetration	Probable safe load
	Feet	*Pounds*
Soft mud	15	4, 500
	30	10, 000
Soft clay	10	7, 000
Compact silt	15	10, 000
	20	13, 000
	30	20, 000
Stiff clay	10	15, 000
	15	23, 000
	20	30, 000
	30	45, 000
Compact sand	8	16, 000
	10	20, 000
	12	24, 000
	15	28, 000
	20	36, 000
	30	48, 000
Sand and gravel	8	20, 000
	10	24, 000
	12	28, 000
	15	34, 000
	20	43, 000
	30	60, 000

62. **Footings.**—*a.* Bank seats and trestle footings must have a sufficiently large area of bearing to prevent their sinking into the soil. If the total of the live and dead loads to be carried is divided by the safe bearing capacity of the soil, the result is the required bearing area. Frequently the area of the lower sill of a trestle is sufficient in itself to afford adequate bearing, but, if not, footings, generally called mudsills, are placed beneath it to increase the area bearing upon the soil. The long dimension of the mudsill is placed perpendicularly to the sill of the trestle and the trestle is placed upon the middle of this footing. The portion of the mudsill that projects beyond the trestle sill acts as a cantilever beam and must have adequate thickness to resist the bending stresses caused by the upward pressure of the ground. The thickness required for various loadings is given in the table following.

TABLE XXIV.—*Safe unsupported projection of timber mudsills in feet*

Distributed load per square foot	Depth of timber					
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches
¾ ton	0.55	1.09	1.63	2.18	2.72	3.27
1 ton	.47	.94	1.41	1.89	2.36	2.83
1½ tons	.38	.77	1.16	1.54	1.92	2.31
2 tons	.33	.67	1.00	1.33	1.67	2.00
2½ tons	.31	.63	.94	1.26	1.57	1.89

b. Bearing power of soils.—For the purposes of military bridges it may be safely assumed that practically all ground will support three-fourths of a ton to the square foot. Soft clay will take 1 ton and firm sand and gravel from 2½ to 4 tons.

63. Approaches.—*a.* On approaches to bridges of less than 100 feet in span the construction of the abutments and approaches may require more time than the erection of the bridge itself. Accordingly, in determining the final height of bridge piers and abutments, care must be taken to see that the bridge floor is at such a height that the work on the approaches will be reduced to a minimum. In rebuilding a demolished bridge, this will ordinarily mean that the floor of the bridge must be placed at about the height of the existing roadway.

b. When new approaches are laid out or old ones corrected, the following should be sought:

(1) A straightway approach on each end of the bridge for at least 150 feet.

(2) A right-angle crossing of the stream or as nearly as this is practicable.

(3) Level or up-grade approaches rather than down-grade, but not on a slope exceeding 1 in 15 if it can be avoided.

c. Approach road.—Where the approach is soft, it may be necessary to extend the flooring of the bridge some distance beyond the end of the bridge or, in effect, to construct a plank road for a short distance. Where the approach is firm, it may not be necessary to use approach planking, but if the roadway has been excavated beyond the end dam or if it must be filled up, great care should be taken in placing the filling. The fill should consist preferably of rock and should be well tamped. The road at the end of the bridge should be surfaced with road metal, corduroy, or planking. The road surface should be about an inch above the elevation of the bridge flooring, in order to avoid shocks and possible displacements of the bridge due to vehicles striking against its end. Where the bridge is narrower than the approach road, it may be desirable to extend the curbs and the handrail about 20 feet beyond the bridge at an angle to the sides of the road. These curbs may be supported by stakes driven into the ground.

64. Abutments.—*a. Component parts.*—A bridge abutment consists of three distinct parts:

(1) A bank seat which supports the bridge span.

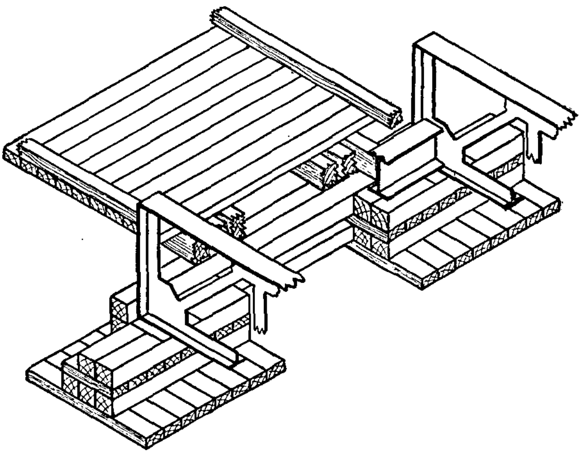


FIGURE 34.—Typical abutment

(2) The connection between the bridge and approach.

(3) The retaining walls or other arrangement provided to prevent the earth from sloughing off beneath the bank seat.

b. The bank seat.—(1) The bank seat usually consists of two parts:

(*a*) A bridge seat or timber sill upon which the end of the bridge span rests directly.

(*b*) Timber footings or mudsills which serve to distribute the load over a greater area.

(2) The bridge seat usually consists of large timbers placed at right angles to the axis of the bridge. These timbers in turn rest on a flooring of timber mudsills or footings placed directly on

the ground but at a sufficient distance from the edge of the bank for the natural slope of the ground to pass in front of the mudsills. The number of the footings will be such as to distribute the ground pressure over a large enough area to prevent settling.

(3) For heavy steel bridges it is usually necessary to place a metal bearing plate between the bridge span and the seat to distribute the load over a sufficiently large area to prevent crushing the wooden sill.

c. Natural ground slopes.—Sand, gravel, dry clay, loam, and mixtures thereof will stand on a slope of three vertical to four

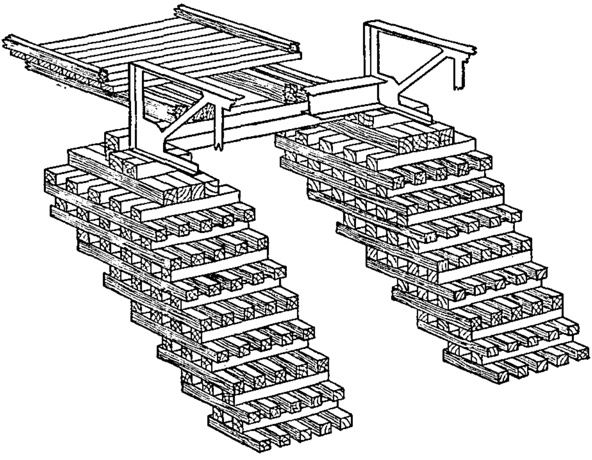


FIGURE 35.—Cribbed abutment

horizontal; wet clay or loam will stand on a slope not steeper than one vertical to two horizontal.

d. Retaining walls.—The object of retaining walls is to prevent the earth from sloughing away from beneath the bank seat and to enable the bank seat to be brought out farther toward the crossing with a view to shortening the span. Either sheeting held in place by piles or braced frames may be used for this purpose. When the water is likely to rise above the base of the crib the latter should be filled with rock and loose rock should be piled outside and around it.

e. Prevention of scour.—For small bridges the cross section of the stream is generally least at the point where the bridge is located. This may have been the controlling factor which led to locating the bridge at this point, or it may have been the result of filling in caused by the demolition of the old bridge, or the caving in of part of the old approaches. In any event, the natural cross section is always reduced at the bridge site, and the velocity of the stream and the scouring action are consequently greater. This leads to the necessity of guarding against scouring away the toe of the bank beneath the bridge, resulting in caving from beneath the bank seat and scouring away of the bank seats themselves during floods. Scouring can be prevented by placing stone riprap between the high-water level and the toe of the bank. This riprap or paving should be carried well up the bank and, if possible, around the bank seats. It is particularly important to carry the riprap around the sides of the bank seats and to about the same elevation, if there is any possibility of the stream rising to that elevation.

65. Spacing of stringers.—Stringers should be placed as nearly as practicable under the wheel tracks so that the strength and wear of the floor planking may be fully utilized and to insure that each stringer receives its share of the load. Typical arrangements are shown in Figure 36. Wooden stringers should be separated by an air space of at least an inch, whenever possible. When time permits and material is available, it is a good plan to bolt the stringers together on each side of the bridge with ¾-inch bolts, placing spacing blocks of wood between the stringers. These blocks should be 6 inches in width, an inch in thickness, and the depth of the stringer in length.

66. Simple stringer bridge.—A simple stringer bridge is a single span bridge in which the stringers rest directly on the bank seats. No trusses and no intermediate supports are provided. Figure 37 shows the typical arrangement of a stringer bridge. Any form of stringers may be used.

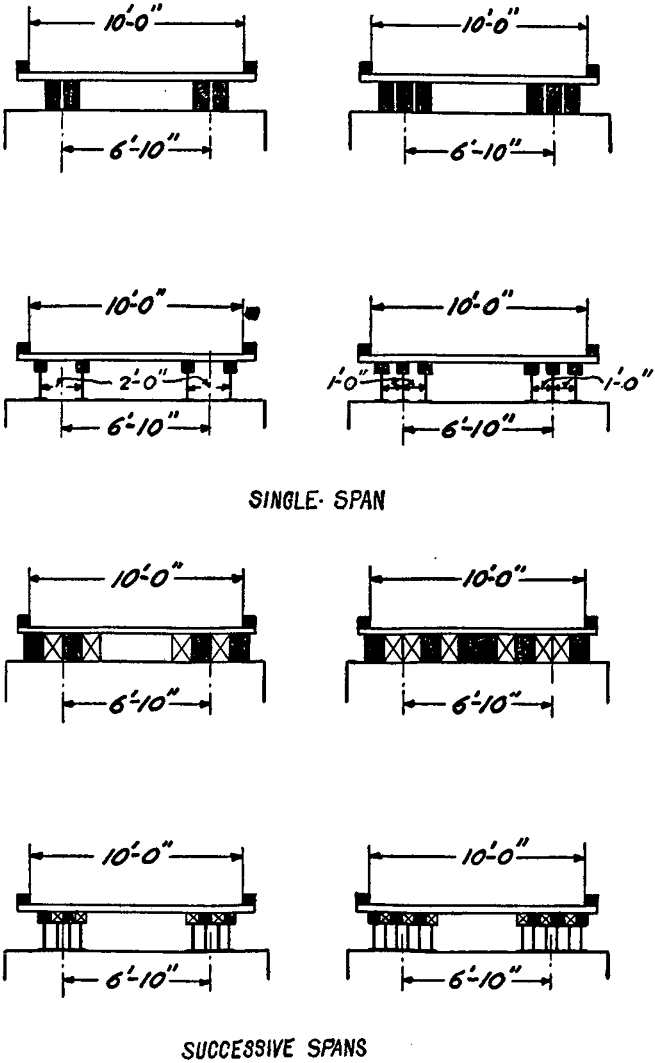


FIGURE 36.—Typical arrangement of stringers

TABLE XXV.—*Bill of materials for simple stringer bridge (fig. 37)*

Number of pieces	Name of member	Commonly used size	Remarks
	Footings	4 by 10 inches	Number depends on bearing area required.
	End dam	4 by 10 inches	As required by approaches.
	Bridge seats	6 by 12 inches	One at each end of span.
	Stringers		Size and number to be computed (par. 58).
	Floor planks	4 by 10 inches by 11 feet.	Or equivalent in other widths.
	Curbs	6 by 6 inches or 4 by 6 inches.	Length depends on span.
	Handrail	4 by 4 inches	Do.
	Handrail posts	4 by 4 inches by 4 feet.	At about 5-foot intervals.
	Handrail braces	4 by 4 inches by 4 feet.	One for each handrail post.
	Bolts with nuts and washers.	14 by ¾ inch	For fastening curbs; one every 3 feet.
	Driftbolts	20 by ¾ inch	One per stringer at each bridge seat.
	Wire spikes	9 by ⅜ inch	One per floor plank per stringer.
	Wire nails	50d	For fastening handrail.

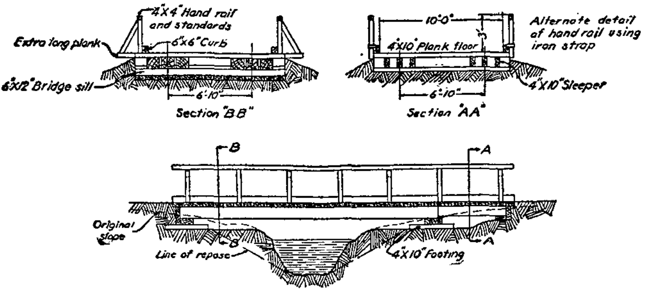


FIGURE 37.—Typical design of stringer bridge showing alternate arrangement of the abutments

67. The Cheney portable artillery bridge.—This is a simple, easily constructed portable bridge designed for the use of divisional artillery. It is so built that it can be transported on artillery caissons. The span is 12 feet. The bridge is used to cross narrow obstacles, ditches, trenches, shell holes, etc., and is generally taken up after use and carried along for use at the next obstacle. It is constructed in two sections, the width of each section being 4 feet. Two sections are necessary for one width of road. The following is the material required for 12 feet (2 sections) of this bridge:

12 timbers 2 by 4 inches by 4 feet.
8 timbers 3 by 8 inches by 12 feet.
52 timbers 2 by 6 inches by 4 feet.
25 pounds 20d nails.

Two sections weigh about 1,440 pounds and are a load for 1 caisson. (See fig. 38.)

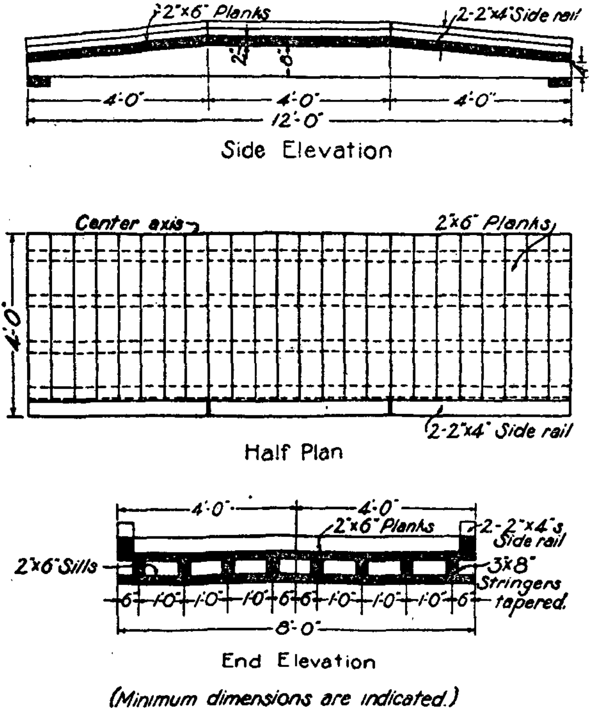


FIGURE 38.—Portable artillery bridge to take 155-mm. howitzer gun carriages. Maximum axle load of 3 tons

68. Timber trestles.—Figure 39 shows a typical timber trestle bridge. The construction indicated is of the simplest kind and can easily be done by unskilled labor. Joints are square and are fastened with scabs or driftbolts. Round timber of suitable size may be used instead of the sawed timber shown, in which case the caps and sills should be roughly squared. Bracing is not required for spans of less than 8 feet in height. For spans between 8 and 16 feet high a single pair of braces will suffice. For heights exceeding 16 feet two pairs of bracings are

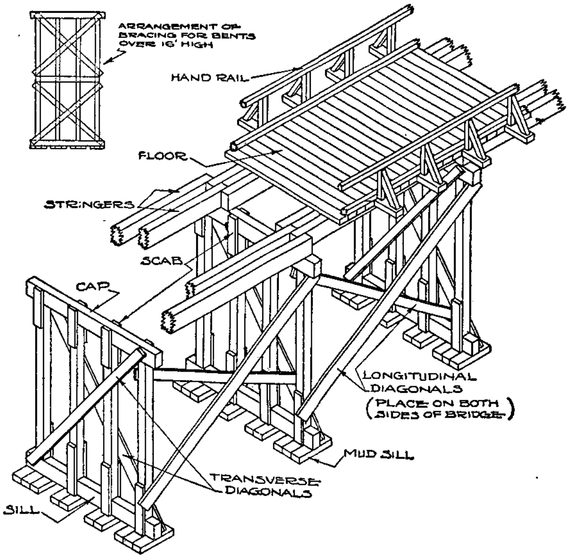


FIGURE 39.—Timber trestle—single story

used as shown. The longitudinal bracing should be continuous throughout the bridge. For spans exceeding 24 feet and where the available lengths of timber require it the multiple story trestle is used. For very high structures, where there is any question of lateral stability, the outside posts must be battered to give a wider base or struts or guys must be used to brace the bents.

TABLE XXVI.—*Bill of materials for timber trestle bent, single story low (fig. 39)*

Number of pieces	Name of member	Commonly used size	Remarks
4	Posts	8 by 8 inches	Length depends on height of trestle.
2	Transverse diagonals.	2 by 10 inches	Do.
4	Longitudinal diagonals.	2 by 10 inches	Length depends on span and height.
1	Cap	8 by 12 inches by 12 feet.	
1	Sill	8 by 12 inches by 12 feet.	
10	Mudsills	4 by 12 inches by 2 feet 4 inches.	
12	Scabs (if used)	2 by 8 inches by 2 feet 4 inches.	Two per joint except where brace interferes.
8	Driftbolts	14 by ¾ inch	Two per post, to fasten cap and sill.
120	Wire nails	60d	For scabs and braces.

The materials for one bent 14 feet high weigh about 1½ tons and are a load for one 1½-ton truck.

TABLE XXVII.—*Bill of materials for timber trestle bent, single-story high (fig. 39)*

Number of pieces	Name of member	Commonly used size	Remarks
4	Posts	8 by 8 inches	Length depends on height of trestle.
4	Transverse diagonals.	2 by 10 inches	Do.
8	Longitudinal diagonals.	2 by 10 inches	Length depends on span and height.
1	Transverse horizontal.	2 by 10 inches by 11 feet.	
2	Longitudinal horizontal.	2 by 10 inches	Length depends on span.
1	Cap	8 by 12 inches by 11 feet.	
1	Sill	8 by 12 inches by 11 feet.	
8	Driftbolts	14 by ¾ inch	Two per post, to fasten cap and sill.
10	Mudsills	4 by 10 inches by 3 feet 8 inches.	
12	Scabs	2 by 8 inches by 2 feet 4 inches.	If used, two per joint except where brace interferes.
120	Wire nails	60d	For scabs and braces.

The materials for one bent 22 feet high weigh about 2¼ tons and are a load for one 3-ton truck.

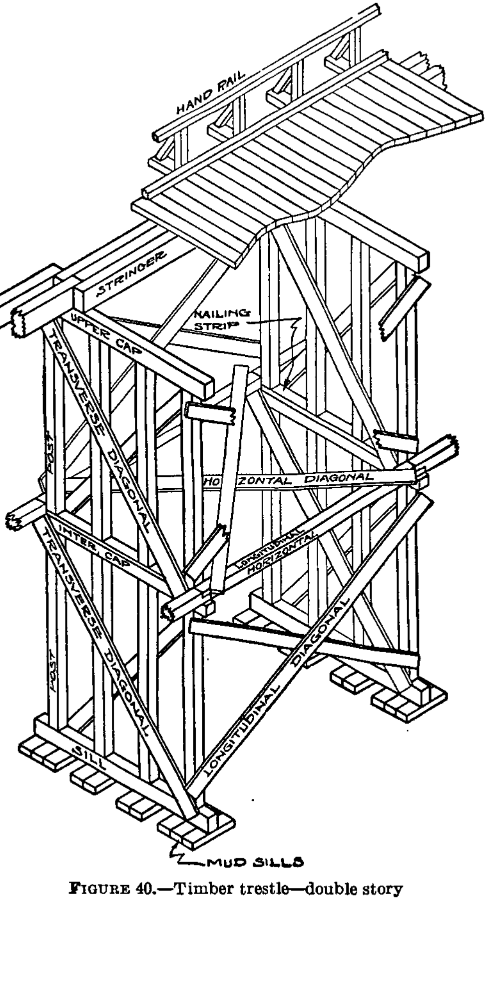


FIGURE 40.—Timber trestle—double story

TABLE XXVIII.—*Bill of materials for timber trestle bent, double story (fig. 40)*

Number of pieces	Name of member	Commonly used size*	Remarks
8	Posts	8 by 8 inches	Four per story.
1	Cap, upper	8 by 12 inches by 12 feet.	
1	Cap, intermediate	8 by 8 inches by 12 feet.	
1	Sill	8 by 12 inches by 12 feet.	
10	Mudsills	4 by 10 inches by 3 feet 8 inches.	
1	Nailing strip	3 by 8 inches by 12 feet.	At foot of posts in upper story.
4	Transverse diagonals.	2 by 10 inches	Length depends on height of story.
[illegible]	Longitudinal diagonals.	2 by 10 inches	Length depends on span and height.
2	Horizontal diagonals.	2 by 10 inches	Length depends on span.
2	Longitudinal horizontals.	8 by 8 inches	Do.
12	Drift bolts	14 by ¾ inch	One per post at caps and sill.
16	Scabs	2 by 8 inches by 2 feet 4 inches.	If used, two per joint except where brace interferes.
200	Wire spikes	60d	

The materials for one bent 22 feet high weigh about 2½ tons and are a load for one 3-ton truck.

69. Plank trestle.—Where large bridge timbers are not available, a trestle may be built up of plank. Figure 41 shows such a trestle to be used for heights not exceeding 16 feet. It should be remembered that a post built up of planks does not have the same column strength as a solid post of the same cross section. Special care must therefore be taken to securely brace a plank trestle.

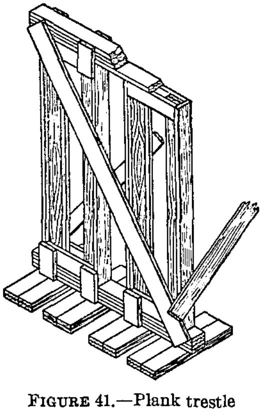


FIGURE 41.—Plank trestle

70. Pile bents.—*a. Definitions.*—A pile bridge is one in which the bents consist of piles (see fig. 42). Piles are posts driven into the ground and deriving their supporting power either from the underlying strata or from friction between the ground and the penetrated portion of the pile. The large end of the pile is called the butt, the smaller end, the tip.

b. Selection of piles.—Round piles should always be used in field operations. Square piles may be used but are more difficult to handle in driving. Piles should be of straight sound timber. The butt should be cut off square; the tip should not be

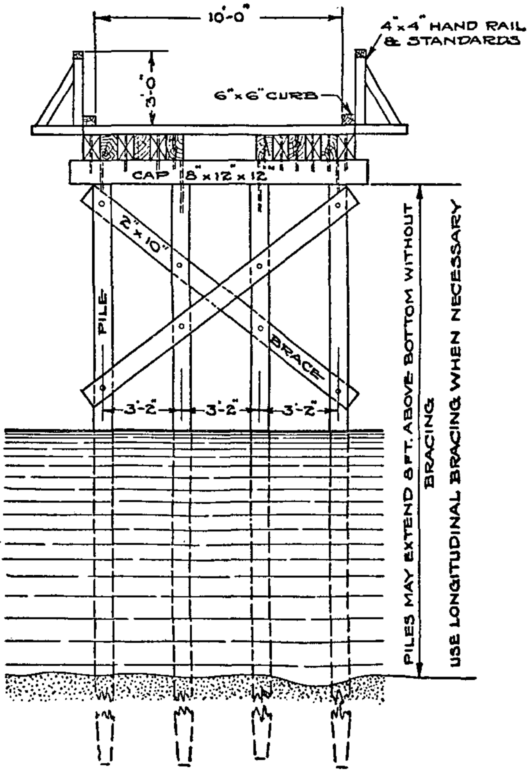


FIGURE 42.—Pile bent

pointed, as a pointed tip is apt to break or shatter. The length of pile to be used depends upon the probable penetration. This may be determined by driving test piles. For tall pile bents it is desirable to batter the outside piles. The cap is attached to the piles with driftbolts, the holes having been previously drilled for their reception. Piles may extend 8 feet above the bottom without bracing. For greater heights a pair of transverse diagonals is used on each bent and longitudinal diagonal braces are used between bents.

TABLE XXIX.—*Bill of materials for pile bent (fig. 42)*

Number of pieces	Name of member	Commonly used size	Remarks
4	Piles, round	14 inches at butt 8 inches at tip.	Length depends on height of bent and probable penetration.
1	Cap	8 by 12 inches by 12 feet.	
2	Transverse diagonals.	2 by 10 inches	Length depends on height of bent.
4	Longitudinal diagonals.	2 by 10 inches	Length depends on span and height.
4	Driftbolts	20 by ¾ inch	One per pile, to fasten cap.
25	Wire spikes	9 by ⅜ inch	For scabs and braces.
6	Scabs	2 by 8 inches by 3 feet.	If used, two per joint except where brace interferes.

71. Trestle piers.—For very heavy bridges such as long truss or I-beam bridges, a pier consisting of two trestles framed together gives a better support than a single bent. The two trestles give greater stability and stiffness and also facilitate the seating of the bridge span. In single trestles corbels or bolsters would have to be provided to give sufficient bearing. Stiffness and stability require that the columns in a pier for a light bridge be at least 8 by 8 inches in cross section, although actual design may show smaller sizes sufficient. For heavy bridges the columns should be 12 by 12 inches. Figure 43 shows a typical trestle pier structure. The pier should be placed on firm, undisturbed ground, and never upon a fill if it can be avoided. Beds for the mudsills under water should be excavated evenly. Trestles must be placed symmetrically on the mudsills. Often the excavation for mudsills can be filled with tamped broken stone. Where there is considerable scour, a bulkhead or heavy riprap should be placed around the pier.

72. Pile piers.—A pile pier is similar to the trestle pier described in paragraph 71 except that piles are used instead of posts resting on sills. A pile pier consists of two pile bents spaced 4 feet apart. The piles must be driven to a sufficient depth to have each safely support its proportionate share of the load.

73. Crib piers.—Timber cribs (see fig. 44) make very good piers for military bridges. They are adapted to nearly all sites and are easy to erect, but require much timber. They may be constructed of round poles or logs or of sawed timbers. In dry situations the cribs are built on the site. The part of a crib that is to stand in water must be adapted to form a cage for the ballast. Enough of the ballast to overcome the flotation of the wood should be so confined that it can not escape. For the rest, it is better to leave the ballast free to run out through the floor

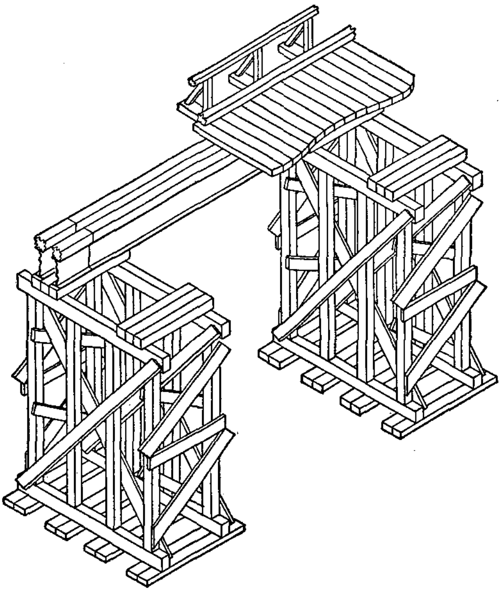


FIGURE 43.—Trestle piers

of the crib and fill any cavities in the bottom which may exist or be formed by the scour of the current. The sides of the crib must be adapted to the ballast to be used. If large stones are available the full interval may be left between the timbers but if the ballast is small the timbers must be dapped. To make the spaces smaller it may even be necessary to plank the sides of the crib. To resist the outward thrust of the ballast the timbers may project in full size a foot or two at each end so that each one rests in a notch cut in the one below. For cribs made of squared timbers two planks nailed in the outside of the corners will resist the tendency of the ballast to displace the timbers. In all cribs the timbers should be spiked together at the outer corners, and the vertical corner posts both inside and outside may be used, wired or bolted together. Timbers of the size used in corduroy roads are satisfactory for crib construction.

74. Truss bridges.— *a. Definition.*—A truss bridge is one in which the roadway loads are transmitted from the floor system to the bridge abutments or piers by means of a truss. A truss is a compound beam, the parts of which are arranged to form one or more triangles in the same plane. The members of a truss are subjected to longitudinal stresses (compression or tension) only.

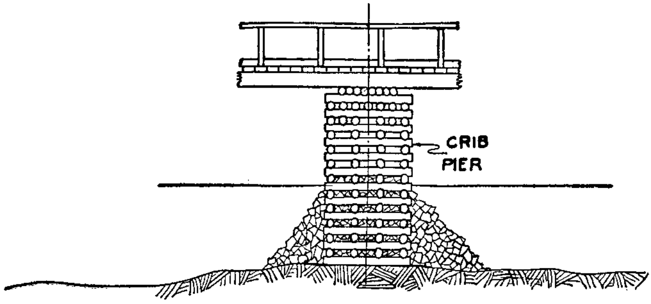


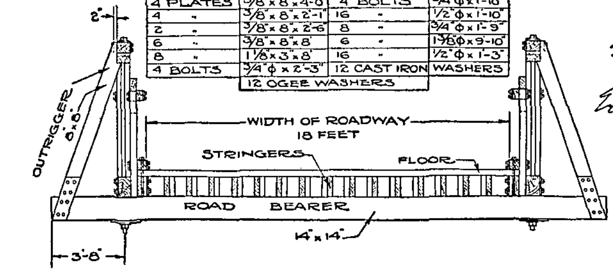
FIGURE 44.—Crib pier

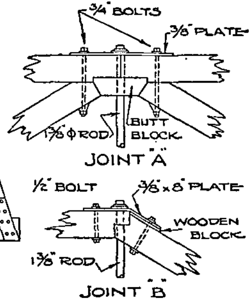
If the roadway is supported on the top chord, the bridge is called a deck bridge; if on the lower chord, a through bridge.

b. Wooden trusses.—Figure 45 shows a 48-foot span wooden truss of the Howe type. This truss is capable of passing all divisional loads. It consists of two parallel chords of solid timber divided by vertical rods into equal panels each of which has diagonals in compression. The top chord is in compression, the lower chord in tension. The lower chord as shown consists of a single timber 48 feet long. If timbers of this length are not obtainable it is necessary to make one or more splices in the lower chord. The simplest splice is made by butting the ends of the timbers and fastening them by bolts passing through wooden fishplates on either side of the joint. Care should be taken to use enough bolts to develop the strength of the lower chord and the nuts on the bolts should be drawn up tight so as to develop

BILL OF METAL

ITEM	SIZE	ITEM	SIZE
4 PLATES	3/8" x 8" x 4'-0"	4 BOLTS	3/4" φ x 1'-10"
4 "	3/8" x 8" x 2'-1"	16 "	1/2" φ x 1'-10"
2 "	3/8" x 8" x 2'-6"	8 "	3/4" φ x 1'-9"
6 "	3/8" x 8" x 8"	6 "	1 3/8" φ x 9'-10"
8 "	1 1/8" x 3" x 8"	16 "	1/2" φ x 1'-3"
4 BOLTS	3/4" φ x 2'-3"	12 CAST IRON	WASHERS
	12 OGEE WASHERS		





BILL OF TIMBER

ITEM	No.	SIZE	LENGTH
BRIDGE	2	3" x 12"	22'-0"
LOWER CHORD	2	8" x 12"	48'-0"
ROAD BEARERS	3	14" x 14"	27'-8"
STRINGERS	68	3" x 12"	13'-0"
FLOOR PLANKS	48	4" x 10"	19'-0"
CURB	6	6" x 6"	17'-0"
END POST	4	8" x 8"	13'-0"
DIAGONAL STRUTS	4	8" x 8"	13'-0"
TOP CHORD	4	8" x 8"	12'-0"
HAND RAILS	8	4" x 6"	13'-0"
HAND RAIL POSTS	10	4" x 6"	6'-0"
BUTT BLOCKS	2	6" x 8"	2'-0"
OUTRIGGERS	6	8" x 8"	9'-0"
OUTRIGGER SCABS	12	3" x 8"	3'-0"

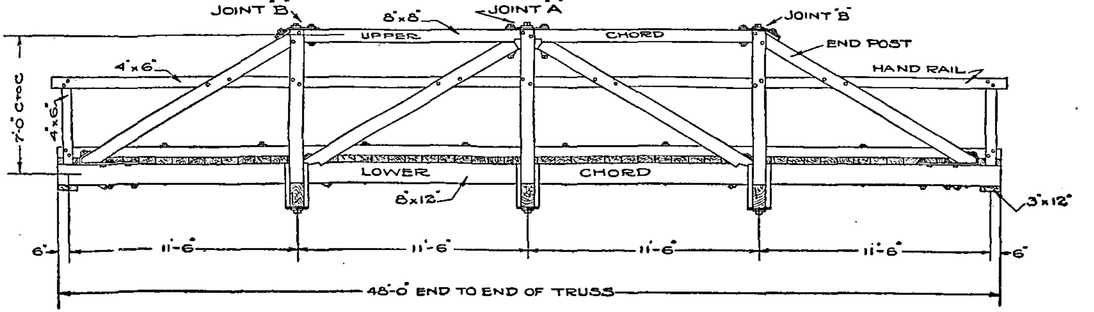


FIGURE 45.—Wooden truss bridge

the maximum friction between the fishplates and the chord timbers.

c. Demountable steel trusses.—Figure 46 shows a portable steel highway bridge of the box-girder type consisting of end sections and intermediate sections. The intermediate sections are interchangeable and any desired number may be used. Each additional intermediate section used extends the bridge 11 feet. This bridge will carry the 155-mm. gun, drawn by a 10-ton tractor, over spans up to 100 feet. Four girders are placed side by side and the flooring is laid across the top chords and spiked to nailing strips. Each end section is 11 feet 6 inches long and weighs

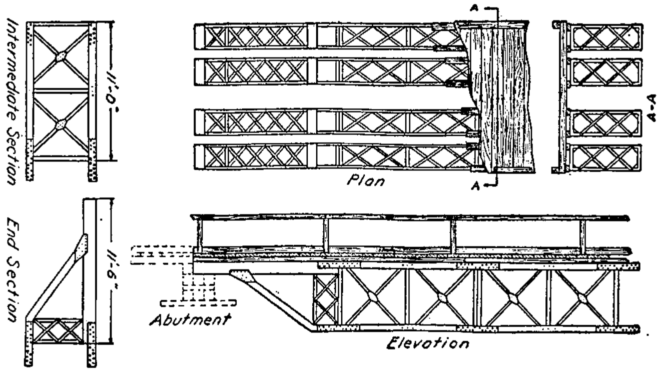


FIGURE 46.—Demountable steel highway bridge

about 1,350 pounds; each intermediate section weighs about 1,340 pounds.

75. Suspension bridges.—*a. General.*—A suspension bridge is one in which the roadway is supported upon cables suspended between towers and other supports on opposite sides of a chasm. As the stability of a suspension bridge depends upon the anchorage to which the ends of the cables are fastened the bridge site should be chosen where the banks are of sound rock or earth and at about the same level. The cables are stretched between the towers allowing a dip in the cables, at the center, of from one-tenth to one-fifteenth of the span. A deep curve causes less stress in the cable and does not require the anchorages to be placed so far from the towers; while a flat curve is less liable to oscillation, but loses form more quickly from stretching. Lateral oscillation of the span, due to moving loads and wind, may be provided for by guys taken from the center of the bridge and secured to holdfasts on the banks as far to the right and left of the bridge as is convenient. The roadway hangs below the cables on slings which support the road bearers upon which stringers, flooring, guard rail, and handrails are placed.

b. Cables.—Under the assumption that the slings are at such close intervals that the loading on the cables may be considered uniformly distributed, the cable takes the form of a parabola. The maximum tension in the cables occurs at the towers. The formula for determining this tension is—

$$T=\frac{1}{2}\sqrt{S^2+\left[\frac{L}{4h}\ (S+W)\right]^2}$$

in which T=the maximum cable tension (at towers).
W=the concentrated live load on the bridge.
S=the sum of all loads on the bridge.
L=the span in feet.
h=the dip in the cable in feet.

When a cable of suitable size to withstand the maximum stress is not available, a cable may be built up of small ropes or wire stretched and lashed together. The length of cables between towers equals $L+\frac{8h^2}{3L}$. To this must be added the length of cable from the towers to the anchorages, plus the turns around the anchorages, to get the total length of cable required.

c. Slings.—The length of slings from point of attachment on the cable to the horizontal plane through the lowest point of the cables may be determined from the following formula:

$$y=\frac{4h}{L^2}x^2$$

in which y=length of the sling in feet.
x=distance from the middle point of the bridge to the sling in feet.
h=the dip of the cable in feet.
L=the span in feet.

TABLE XXX.—*Sling lengths*

Dip h	Value of y when x =								
	$0.1\frac{L}{2}$	$0.2\frac{L}{2}$	$0.3\frac{L}{2}$	$0.4\frac{L}{2}$	$0.5\frac{L}{2}$	$0.6\frac{L}{2}$	$0.7\frac{L}{2}$	$0.8\frac{L}{2}$	$.09\frac{L}{2}$
$\frac{L}{10}$	$0.001L$	$0.004L$	$0.009L$	$0.016L$	$0.025L$	$0.036L$	$0.049L$	$0.064L$	$0.081L$
$\frac{L}{11}$	$.0009L$	$.0036L$	$.0082L$	$.0145L$	$.0227L$	$.0327L$	$.0445L$	$.0582L$	$.0736L$
$\frac{L}{12}$	$.0008L$	$.0033L$	$.0075L$	$.0133L$	$.0208L$	$.03L$	$.0408L$	$.0533L$	$.0675L$
$\frac{L}{13}$	$.0008L$	$.0031L$	$.0069L$	$.0123L$	$.0192L$	$.0277L$	$.0377L$	$.0492L$	$.0623L$
$\frac{L}{14}$	$.0007L$	$.0029L$	$.0064L$	$.0114L$	$.0179L$	$.0257L$	$.035L$	$.0457L$	$.0579L$
$\frac{L}{15}$	$.0007L$	$.0027L$	$.006L$	$.0107L$	$.0167L$	$.024L$	$.0327L$	$.0427L$	$.054L$

The slings are attached to the road bearers by a clove hitch and seizing and are attached to the cable by a round turn and seizing. The tension in the slings equals the reaction at the end of the road bearer under the assumed conditions of loading and may be determined in the same manner as described in paragraph 58 for determining the maximum end shears in stringer bridges. The dead load must, of course, be added to the stress caused by live loads.

d. Towers.—The towers are designed in the same manner as timber trestles when the load on the tower has been determined. The angle between the direction of the cable at the tower and the horizontal expressed in terms of its tangent is $\frac{4h}{L}$. The sine of this angle is

$$\frac{4h}{\sqrt{L^2+(4h)^2}}$$

When the backstay has the same angle of direction as the suspension cable the reaction at the tower is vertical and is given by the formula:

$$P=2\ T \text{ sine } \theta$$

in which P=the load (compression) brought upon the tower by one cable, in pounds.

T=the tension in the cable at the tower, in pounds.

θ=the angle of direction of the cable from the horizontal at the tower.

e. Anchorage.—Under the assumptions made in *d* above the horizontal force exerted in the anchorages equals T cosine θ. The anchorage may consist of deadmen or holdfasts designed as described in paragraph 98.

SECTION II

RECONNAISSANCE

76. Kinds of reconnaissance.—Bridge reconnaissance may be of several kinds, depending upon the uses to which the information so obtained is to be put. *Tactical bridge reconnaissance* is made to determine bridge data with reference to tactical operations. *Technical bridge reconnaissance* may be made to determine the carrying capacity of existing bridges or to obtain data which will become the basis of new construction. Another form of technical reconnaissance consists of routine inspections in connection with maintenance.

77. Sources of information.—Information for any purpose in connection with bridge operations may be obtained from maps, aerial photographs, local inhabitants, special intelligence reports, prisoners, and personal reconnaissance. While all of these sources of information should be used the personal reconnaissance is in any case necessary in order to verify other information and to obtain up-to-date information.

78. Reconnaissance party.—*a. Personnel.*—The reconnaissance party should always include an engineer officer. This is especially necessary when tactical commanders are reconnoitering in connection with river-crossing operations when, although tactical considerations may predominate, the advice of an engineer is necessary in order that technical considerations may not be overlooked. An engineer reconnaissance party should include, if possible, the commander of the troops who will do the construction. The party need not be large, often the leader with one assistant being sufficient.

b. Equipment.—The reconnaissance party should be equipped with transportation, prismatic compass and tape for measuring the width of the stream, hatchet for cutting and driving stakes, string and plummet for making soundings and, if circumstances permit its use, a skiff. A camera may be found useful for taking pictures to be incorporated in the reconnaissance report.

c. Report.—The report of the reconnaissance party should include a clear explanation of all data obtained illustrated with one or more sketches, and should recommend the type of bridge to be built or the repairs to be made. It should include a bill of materials and list of tools, together with an estimate of labor and time required for the construction and the transportation necessary; the condition and location of the routes approaching and leading away from the bridge site should be covered in the report. A form for making the report of a bridge reconnaissance is shown in paragraph 81.

79. Tactical reconnaissance.—The dominant considerations are the tactical requirements of concealment of preparation, surprise as to the time and location of the bridge operations and speed of construction. Tactical considerations may fix the location of a bridge within certain limits, but in order that it may be accessible the location of existing approach roads should be given consideration. The type of bridge to be used depends upon technical considerations such as the bridge site, the available materials, and the character of the loads to be transported, but tactical considerations, such as the necessity for the immediate passage of certain combat loads, may dictate the construction of a very light structure, at least in the early stages of the operation, to be reinforced or replaced by a heavier structure as the operation progresses and as the need arises for the passage of the heaviest army loads.

80. Reconnaissance to determine the capacity of existing bridges.—*a. General.*—Except in the simplest cases, the accurate determination of the carrying capacity of an existing bridge requires considerable time. It frequently occurs, however, that an officer is called upon to give a decision at such short notice that complete calculations are impossible. In such cases, the suggestions and rules of thumb which follow may assist in forming a judgment as to the capacity of an existing bridge.

b. Capacity of floor planks.—Flooring may be considered to be sufficiently strong to carry all loads which the understructure will carry if the thickness of the floor planks in inches is at least equal to the clear distance between stringers in feet.

c. Capacity of simple stringer bridges.—Investigate the stringers for strength against bending. Taking into consideration the kind of flooring apt to be found, it is reasonably safe to assume that the load will not be equally divided among the stringers. It is a fair assumption that one-third of the total load upon the span might have to be carried by any one stringer and that two-thirds of this load, that is two-ninths of the entire load on the span centered in the middle of the stringer will give an approximately equivalent bending stress. Based upon this hypothesis approximate simple formulas for judging the strength of stringers are—

$$W=\frac{bd^2}{L} \text{ (for rectangular timber).}$$

$$W=\frac{6d^3}{10L} \text{ (for round timber).}$$

Where W=the maximum permissible load on a single stringer in hundreds of pounds.
b=the breadth of the stringer in inches.
d=the depth of a rectangular stringer in inches, or the diameter of a round timber.
L=the span in feet.

These formulas are based on a working stress of 1,800 pounds per square inch. The factor of safety is about 3. If judgment indicates that this working stress is excessive for the stringers being investigated, the permissible load should be taken as proportionately less. An approximate formula for judging the strength of a steel I-beam is:

$$W=\frac{d^2}{5L}$$

Where W=the maximum permissible load on a single **I** beam in tons.
d=the over-all depth of the **I** beam in inches.
L=the span in feet.

Example: An existing bridge is found to have six rectangular wooden stringers 8 by 10 inch cross section, evenly spaced 2 feet center to center; span 14 feet; floor planks 2 inches thick; What maximum load should the bridge pass?

Answer: The load which any one stringer can pass is, by the formula given above, $W=\frac{8\times10\times10}{14}=57$ hundred pounds. The floor planks being thin, it is assumed that this stringer may have to carry two-ninths of the total load on the span. Therefore the total permissible load on the bridge is $9/2 \times 5{,}700=25{,}650$ pounds.

d. Capacity of pile or trestle bridges.—The flooring and stringers only need be tested, as in *c* above, the poles or posts being assumed to be sufficiently strong to carry the load which the stringers will carry.

e. Capacity of steel trusses.—Investigate only the floor system; that is, the flooring, stringers, the riveted joints at the stringer ends, the cross girders, and the riveted joints supporting the cross girder ends. If these will carry the load required, it may be assumed that the main members of the steel bridge are also sufficiently strong. This procedure is justified, since the heavy, concentrated loads of military traffic will especially affect the floor system, and it is most unlikely that the latter has been designed with a strength out of proportion to the main structure. Test the stringers for bending. If the ends of the stringers rest on the cross girders, the shear need not be calculated; but if they are held to the cross girders by riveted joints, the strength of the riveted joint to withstand the maximum shear should be investigated. Similarly, the strength of the joint at the end of the cross girder should be investigated to see whether the rivets have sufficient strength in shear to carry the load. Special attention should be given to the rivets, and allowance must be made for any rivets which are loose. To test the rivets for tightness, tap them lightly with a hammer. Examine the joint to see whether the rivets are in single or double shear. Determine the size of the rivets. Multiply the number of tight rivets by the shear strength per rivet as given in Table XXXI. This gives the shear strength of the joint.

TABLE XXXI.—*Dimensions and strength of rivets*

[Based on a unit stress of 15,000 pounds per square inch for reconnaissance purposes]

Diameter of rivet head	Diameter of rivet	Area of rivet	Strength in single shear	Strength in double shear
Inches	*Inches*	*Square inches*	*Pounds per rivet*	*Pounds per rivet*
7/8	1/2	0.20	3,000	6,000
1 1/16	5/8	.31	4,600	9,200
1 1/4	3/4	.44	6,600	13,000
1 7/16	7/8	.60	9,000	18,000
1 5/8	1	.79	11,000	22,000

f. Capacity of reinforced concrete bridges.—It is impossible to ascertain from inspection the position or dimensions of the reinforcement, and no satisfactory formula based on the dimensions of the beam can be given. The only guide is that reinforced concrete bridges must necessarily be modern and may therefore be presumed to have been designed to carry loads likely to use the highways passing over them.

g. Capacity of arch bridges in masonry, brick, or concrete.—Table XXXII gives the thickness of arch ring at the crown for arch bridges to carry all loads up to 10-ton axles or 20-ton tanks for various spans up to 100 feet.

TABLE XXXII.—*Arch bridges*

[Crown thickness required for all loads up to and including 10-ton axles or 20-ton tanks]

Span	Thickness of arch ring at crown			Span	Thickness of arch ring at crown		
	Brick in cement	Plain concrete	First-class cut stone (ashlar)		Brick in cement	Plain concrete	First-class cut stone (ashlar)
Feet	*Inches*	*Inches*	*Inches*	*Feet*	*Inches*	*Inches*	*Inches*
10	12	8	8	50	26	22	20
12½	13½	9	9	55	27	23	20½
15	15	10	10	60	28	24	21
17½	16½	11	11	65	29	26	22
20	17½	13	12	70	30	27	23
22½	18	14	13	75	32	28	24
25	19	15	14	80	34	29	25
27½	20	16	15	85	35	30	26
30	21	17	16	90	36	32	28
35	22	18	17	95	38	34	29
40	23	20	18	100	40	36	30
45	25	21	19				

81. Reconnaissance for new construction.—*a. Siting the bridge.*—The final decision in siting a new bridge should always be made on the actual ground. The approaches to a bridge site often involve more work than the construction of the bridge itself. This particularly applies to floating bridges. Tactical bridges may require entirely new approach routes; other bridges should, wherever possible, be sited close to existing routes. Generally a choice of location is possible. The following points should be borne in mind. The channel of a river is in constant state of change due to scouring and silting. The banks are better able to resist scour on straight reaches which are therefore more suitable for new bridge sites; otherwise, protective revetments may be necessary. High banks confine the flood water in the main channel and usually mean less work on approaches. Bridges should cross streams as nearly at right angles as possible since skew spans are usually difficult to erect and they also require longer piers.

Pile piers can not be used on rocky sites. A straight approach should be sought on each side of the bridge for at least 50 yards. Level approaches are best. The height of the bridge level should be such that work on the approaches is reduced to a minimum commensurate with other technical considerations in the design.

b. Cross section of stream.—If the site is not in the possession of our forces, much information may have to be obtained from an examination of aerial photographs. If these are not available, the span of the gap may be determined by triangulation from the shore in possession of our forces. In order to determine the height of the bridge supports an accurate cross section must be obtained by sounding. For narrow streams the following method may be used to obtain the data:

(1) Drive two pickets on the near bank about 3 to 4 feet apart and on the center line of the proposed bridge. (See fig. 47.) Level the pickets with a spirit level. Sight on a third picket, C, on the far bank. Level the top of this picket with pickets, A and B, by use of the hand telescopic level, or by sighting if no level is available. The difference in heights of picket, A, and picket, C, gives the difference in level between the two banks.

(2) Lay off 5-foot distances on a rope line by tagging the intervals with white tape. Stretch this line tightly between pickets, A and C. If a boat is available, take soundings from the boat at the tagged points. Tabulate these soundings. If no boat is available, the data must be obtained in daylight as follows: Stretch the line between the two pickets as before. Cut two more lines, one of which is slightly longer than the distance between the pickets, A and C, and the other twice as long. Fasten one end of each of these lines to a small ring which in turn is passed over the line pulley to picket, C. Pass the longer line of the two attached to the ring through this pulley. Swing the free ends of the ropes attached to the ring to the near bank. By paying out on one of these ropes and pulling in on the other the ring can be made to travel from bank to bank. Run a plumb line through the ring with the free end at picket, A. Put a weight on the other end. To measure the depth run the ring to the desired tape with the plumb line out until the weight hits the bottom. Measure the amount of line paid out beyond picket, A. This gives the desired elevation. Continue this until all points are measured.

c. The character of the bottom.—Often an adequate idea may be formed of the bottom and substrata by driving a pointed spar or light test pile into the soil. Time permitting, a better idea can be obtained by making auger borings. An auger is attached to the desired length of pipe. This is rotated by hand and withdrawn from time to time to bring up samples. A 2-inch auger is needed for very hard soils.

d. Character of the flow.—Examine existing bridges and any other possible sources of information to determine the flood water height, as the bridge must be designed to have sufficient clearance for river traffic and to provide for the passage of flood water.

e. Local materials.—The reconnaissance should determine the nearest sources of materials which may be used in the construc-

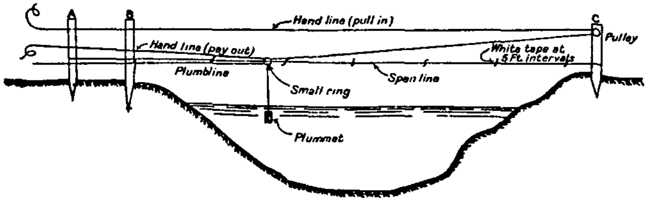


FIGURE 47.—Method of taking cross section (no boat available)

tion. These sources include standing timber of large sizes for the bridge proper; standing timber of smaller sizes which might be used for crib piers or crib abutments, or for corduroying the approach roads; near-by buildings from which timbers may be removed; and local lumber markets or military engineer depots. The location of these sources is of great importance, since the transportation of materials from the rear to the bridge site may be undependable and may delay the construction as well as taking lumber and transportation which might have been saved.

f. Construction camp.—The reconnaissance should determine a suitable location for the camp of the constructing forces during the period of the construction. The camp should be located as near as possible to the bridge site, and should include space for the storage of engineer supplies, the parking of transportation, corralling of animals, rolling kitchens, and latrines. The nearest water supply should be located.

Bridge______________________
Class_______________________
Sheet No. ____ In ____ sheets.

FORM FOR BRIDGE RECONNAISSANCE

Map reference____________________
Date____________________ Party____
(If necessary, use back of sheets, repeat number of headings)

LOCATION

(1) Designation of route____
(Road, railroad, canal, or stream)
(2) Two towns on route____
(3) Name of nearest town, direction and distance from bridge____________________
(4) Stream, canal, road or railroad crossed by bridge____________________________
(5) Local name of bridge____
(6) Remarks____
____
____

DESCRIPTION OF BRIDGE

(7) Type____
(8) Spans____
(9) Total length____
(10) Net length____
(11) Total width____
(12) Width of roadway____
(13) Clearances:
Above roadway { Horizontal____
Above roadway { Vertical____
Under roadway____
(14) Floor system:
(*a*) Flooring____
(*b*) Stringers and floor beams____
(*c*) Curbs, handrails____
(15) Number and width of sidewalks____
(16) Piers____
(17) Abutments____
(18) Wing walls____
(19) Paving____
(20) Maximum loads: Now using bridge ______ Reported capacity_______________
(21) Remarks____
____

DESCRIPTION OF CROSSING

(Make plan and profile on extra sheet showing (*a*) all bridges involved in crossings; (*b*) bridge being reported on.)

(22) One of ------ bridges involved in crossing------------------------------------

----

(23) Character of stream: Maximum depth { Low water------------------------- / High water------------------------- / Observed------------------------- }

(24) Velocity: Feet per second---

(25) Flood per year ------ months---

(26) Amount and character of dêbris carrier at high water-------------------------

----

----

(27) Character of bed and banks of stream--------------------------------------

(28) Approaches:

(*a*) -------end. Straight length------width------height------cut or fill.

(*b*) -------end. Straight length------width------height------cut or fill.

(29) Remarks---

----

(30) Description of connecting roadway between several bridges involved in crossing

----

RECOMMENDATIONS

(31) List in order of practicability for new construction: (Pile bents, trestle, crib supports, etc.)--

(32) Remarks---

----

(33) Estimate of time required for construction---------------------------------

(34) Troops---

(35) Bill of materials (use extra sheet)--

(36) Remarks---

----

82. Routine inspections.—*a. General.*—All bridges in the area occupied by the field forces should be inspected periodically. These inspections should be made at intervals dependent upon the types and importance of the bridges, their condition, and the density of traffic over them. At least one very thorough inspection per month should be made by an officer having special knowledge of bridge construction.

b. Facts to be determined.—Inspections and reports should be made to cover the following points:

(1) To ascertain the amount of deterioration of the structure and to discover weakness or defects.

(2) To determine the safety of the structure under maximum conditions of load, or the limiting safe loads in its present conditions.

(3) To decide upon repairs necessitated by (1) or (2) above.

c. Form for routine inspection report.—It is fully as important to ascertain a change in the condition of the bridge since the last inspection as it is to know its present condition. It is, therefore, desirable to have successive inspections made by the same man and to have the records of the inspection carefully preserved at some central point. A convenient form for periodically reporting bridge inspections follows.

FORM FOR REPORT OF BRIDGE INSPECTIONS

Location................... Bridge No...........

Map sheet.................. Coordinates......................................

On road from..................to.................. Type..................

	Condition			
Inspected by........................				
Date................................				
Alignments: Vertical......................... Horizontal.......................				
Floor system: Pavement......................... Curb and handrails............... Stringers........................ Floor beams......................				
Trusses: Top chord........................ Bottom chord..................... Diagonals........................ Posts............................				
Plate girders.......................				
Pile or trestle bents: Caps............................. Piles or posts................... Sills............................ Braces...........................				
Shoes and end bearings.............. Bridge seats........................				
Masonry: Arches........................... Abutments........................ Piers............................				
General conditions..................				

NOTE.—Fill in condition on lines which are applicable to structure. Use terms "Good," "Fair," "Poor," "Need repairs," "Unsafe." If conditions call for additional remarks, put same on back with proper reference.

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Section III

MAINTENANCE, REINFORCEMENT, AND REPAIR

83. General.—The problem of strengthening existing bridges is often complicated by the necessity of not interrupting traffic over them. This requires the exercise of the greatest care to see that no member is removed without first making provision for carrying its load and that nothing else is done which will reduce the strength of the bridge. In some cases a ponton bridge may be used to divert highway traffic and thus facilitate and hasten the repairs.

84. Correction of bad condition.—*a. Lateral or vertical displacement.*—Determine the particular element of the bridge responsible for the displacement and either renew or strengthen it.

b. Rusted or rotted members.—Replace or strengthen weakened members, or insert additional ones.

c. Mechanical injuries.—Bent or otherwise injured parts should be straightened, strengthened, or renewed.

85. Repairs to floor system.—*a. General conditions.*—First determine whether the floor system is to be repaired so as to enable it to take reduced loads, or so as to utilize the maximum capacity of the bridge.

b. Planking.—If bad, it should be renewed. A temporary improvement may be obtained by placing planks upon the old deck and beneath the wheel tracks, with their lengths in the direction of the traffic and with their outer edges beveled.

c. Curbs and handrails.—Tighten, replace, or strengthen as required.

d. Stringers.—In case it is necessary to replace existing stringers, the decking must usually be removed and relaid after the stringers are replaced. Where there is sufficient room under the flooring, it is sometimes possible to insert additional stringers from below and work them into place. The use of narrower stringers facilitates this. Sometimes, when it is necessary to maintain traffic while the repairs are being made, the bay may be supported temporarily on an independent bent or crib in front of the abutment or next to the pier, jacking the old stringers up enough to permit the new ones to be inserted. If the bridge is a wide one, half of the deck may be repaired at a time.

86. Reinforcing stringer spans.—*a.* One of the simplest methods of strengthening timber bridges is to place an extra bent in the middle of each bay. This immediately increases the capacity of the stringers from two to four times and relieves the adjacent bents. In placing an extra bent, it is necessary to make sure that it actually receives the part of the load which it is intended to support. This is generally done by placing wedges on the cap and beneath the stringers and driving them home. These wedges should have a long taper and should be doubled so that horizontal surfaces come to bear both upon the cap and the bottom of the stringers. The ends of the wedges should not be cut off as it may later become necessary to drive them farther.

b. Where the abutments are of masonry, another method of strengthening a simple stringer bridge is to brace the stringers by diagonal struts running from the masonry to the underside of the stringers. Care should be taken to secure a good seat for the ends of the struts in contact with the masonry, while the other ends should butt against pieces spiked to the underside of each stringer.

87. Repairs to bank seats.—Replace rotted portions by jacking up bridge. In case of uneven settlement, build up to proper height with timber. In case of sloughing of bank, construct braced frame, pile or crib retaining wall, or place plenty of riprap around the toe of the bank.

88. Repairs to pile and trestle bents and bracing.—Weak pile or trestle bents may be relieved of part of their loads by inserting new trestle bents or cribs alongside of them, or in the middle of adjacent spans on cribs or framework. New posts and caps may thus be inserted in trestle bents. Additional piles may be driven by taking up the floor, but this usually involves an interruption of traffic. Pile bents which are decayed or damaged above the water line may be rebuilt by cutting off the piles near the water level and splicing new piles to them, or better by capping them at the water level and superimposing a trestle bent. Weak joints may be strengthened by splices or other fastenings.

89. Correction of bad alignments.—If the bents have been distorted laterally, they may be reinforced by inclined struts inserted in the bent or on the side toward the displacement or by guying on the other side. It is often possible to straighten a deformed bent with tackle, the diagonal braces being first removed and afterwards replaced and securely fastened.

90. Settlement.—Conditions may be improved by driving footing pieces or by thoroughly tamping broken stone beneath the sills. This should be followed by throwing riprap over and around the sills

91. Displacement.—Ice and heavy floating débris are particularly dangerous, and protection against them should be provided if necessary by means of fender piles, protecting bulkheads, or by using large quantities of riprap. Light floating débris may be diverted with floating booms. These protective features, as well as the longitudinal braces, must be arranged so that they will not unduly restrict the flow of the stream during high water.

92. Repairs to masonry supports.—*a. Uneven settlement or insecurity of foundations.*—If this is due to scour, it may be checked by placing riprap around the foundations. If it is due to overload or insufficient bearing power of foundations, there are two methods of treatment. One is to go to the seat of the trouble and rebuild the foundations. This will usually be impracticable under war conditions because of the elaborate plant and time required. The other method, which will usually be employed, is to relieve the weak masonry of its load by means of cribbing or trestle bents placed close to the abutment or pier.

b. Cracks, bulging and sliding of abutments and piers.—Cracks are usually caused by unequal settlement of the foundation as a result of overloading, and the best treatment is to relieve the masonry of its load by using wooden bents or cribbing. If they are due to mechanical injury or age, the damaged portion may be repaired with concrete or rebuilt. Bulging or sliding of abutments is due to excessive pressure generally caused by water in the back fill, and may be relieved by a tile or broken stone drain placed immediately behind the masonry, or by drilling weep holes through the structure. Steel rods anchored to deadmen on the bank and extending through the masonry may also be used to reinforce a weak abutment.

93. Reinforcement of steel and wooden trusses.—Truss members may be reinforced by placing additional struts alongside of compression members and steel rods or cables alongside of tension members. It should be noted that the placing of supports, such as trestles, under the panel points of the truss in some cases may not help the truss and may be decidedly harmful since they may cause reversal of stress in members capable of taking tension only. If the truss is deemed inadequate to support the loads likely to pass over it, the truss itself may be disregarded and the structure may be transformed into a simple stringer bridge by placing a trestle or crib support under each panel point.

94. Repairs to masonry arch bridges.—If masonry arches are damaged so as to prevent their use for all usual military loads, they will usually require replacement rather than repairs, although the remains of the masonry may sometimes be utilized as the abutments and piers of the new structure.

SECTION IV

ERECTION

95. Joints.—The following methods are applicable to joining the sills and caps to the posts of wooden trestles:

a. By driftbolts.—One driftbolt is used from the sill into the foot of each post and one from the cap into the post. Three-quarter-inch holes for the driftbolts are bored. The depth of these holes should be such that the driftbolts will drive 2 inches into the solid wood at the bottom of the hole. In assembling the bent, place the posts the proper distance apart on level ground or on planking if the ground is uneven, and place the caps; then drive the driftbolts from the cap into the posts.

b. By scabs.—Scabbing pieces or fishplates may be pieces of plank 2 inches by 8 inches by about 3 feet long, placed parallel to the posts and nailed on them or bolted across the joints. Two scabbing pieces are used for each joint except where the diagonal pieces interfere. In assembling the bent lay out the posts for one bent and fasten the scabbing pieces on their upper sides at each end except where the post will replace the scabbing piece. Each scab should project about 10 inches beyond the end of the post. The posts are then turned over until the scabbing pieces rest on the ground. Place a sill and cap in their proper positions on these scabbing pieces and against the ends of the posts, and fasten the other scabbing pieces to the upper sides of the posts and sill or the posts and cap. Steel plates properly bored and bolts may be used for scabs.

96. Knots.—*a. Description and uses.*—The following knots are most useful in bridging (see fig. 48 ①, ②, ③, and ④):

(1) *Overhand knot*, used at the end of a rope to prevent unreeving or to prevent the end of the rope from slipping through a block.

(2) *Figure-of-eight knot*, used for purposes similar to (1) above.

(3) *Square or reef knot*, commonly used for joining two ropes of the same size. The standing and running parts of each rope must pass through the loop of the other in the same direction,

that is, from above downward or vice versa; otherwise a granny is made, which is a useless knot that will not hold. The reef knot can be upset by taking one end of the rope and its standing part and pulling them in opposite directions. With dry rope a reef knot is as strong as the rope; with wet rope it slips before the rope breaks, while a double sheet bend is found to hold.

(4) *The thief knot,* commonly mistaken for a reef knot, should be avoided as it will not hold. The figure shows that the end of each rope turns around the standing part instead of around the end of the other, as in a reef knot.

(5) *Single sheet bend, weaver's knot,* used for joining ropes together, especially when unequal in size. It is more secure than the reef knot but more difficult to untie.

(6) *Double sheet bend,* used also for fastening ropes of unequal sizes, especially wet ones, and is more secure than the single sheet bend.

(7) *Two half hitches,* especially useful for belaying, or making fast the end of a rope round its own standing part. The end may be lashed down or seized to the standing part with a piece of spun yarn; this adds to its security and prevents slipping. This knot should never be used for hoisting a spar.

(8) *Round turn and two half hitches,* like the preceding, except that a turn is first taken round the spar or post.

(9) *Fisherman's bend or anchor knot,* used for fastening a rope to a ring or anchor. Take two turns round the iron, then a half hitch round the standing part and between the rings and the turns, lastly a half hitch round the standing part.

(10) *Clove hitch,* generally used for fastening a rope at right angles to a spar or at the commencement of a lashing. If the end of the spar is free, the hitch is made by first forming two loops, placing the right-hand loop over the other one and slipping the double loop over the end of the spar. If this can not be done, pass the end of the rope round the spar, bring it up to the right of the standing part, cross over the latter, make another turn round the spar, and bring up the end between the spar, the last turn, and the standing part. When used for securing guys to sheer legs, etc., the knot should be made with a long end, which is formed into two half hitches round the standing part and secured to it with spun yarn.

(11) *Timber hitch,* used for hauling and lifting spars. It can easily be loosed when the strain is taken off, but will not slip

under a pull. When used for hauling spars, a half hitch is added near the end of the spar.

(12) *Telegraph hitch*, used for hoisting or hauling a spar.

(13) *Hawser bend*, used for joining two large cables. Each end is seized to its own standing part.

(14) *Bowline*, forms a loop that will not slip. Make loop with the standing part of the rope underneath, pass the end from below through the loop, over the part round the standing part of the rope, and then down through the loop. The length of bight depends upon the purpose for which the knot is required.

(15) *Bowline on a bight.*—The first part is made like the above with the double part of a rope; then the bight is pulled through sufficiently to allow it to be bent past the loop and come up in proper position. It makes a more comfortable sling for a man than a single bight.

(16) *Running bowline.*—(*a*) To sling a barrel or box horizontally make a bowline with a long bight.

(*b*) To sling a barrel vertically, make an overhand knot on top of the two parts of the rope; open out the knot and slip each half of it down the sides of the casks; secure with a bowline.

(17) *Cat's-paw.*—Form two equal bights; take one in each hand and roll them along the standing part till surrounded by three turns of the standing part; then bring both loops (or bights) together and pass over the hook of a block, where the hook is moused with yarn.

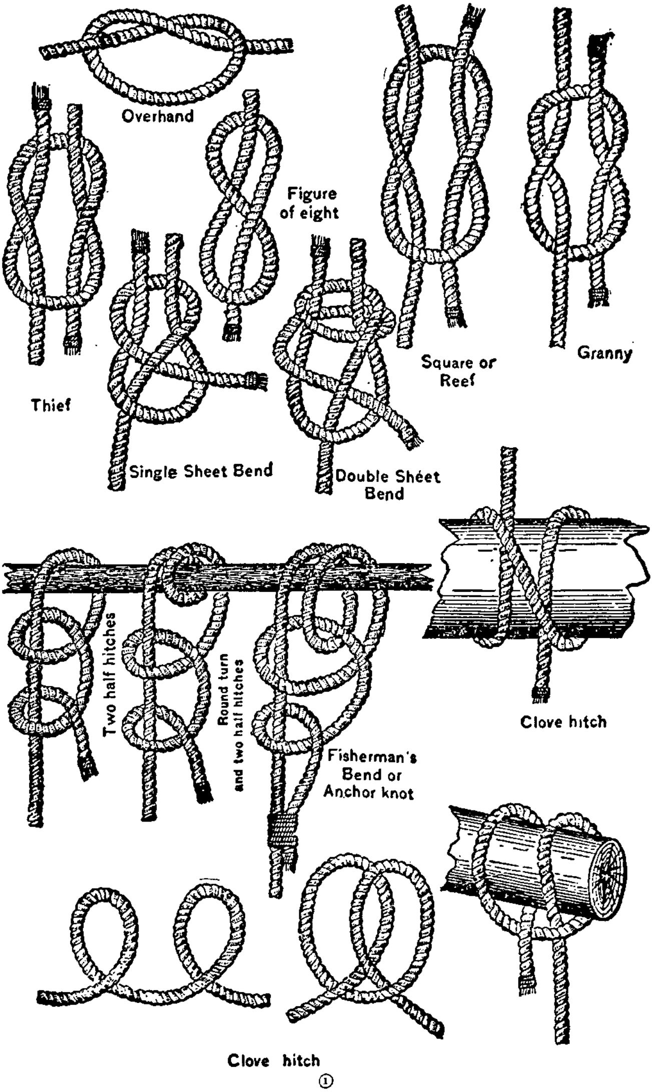
(18) *Sheep shank*, used for shortening a rope or to pass by a weak spot; a half hitch is taken with the standing parts around the bights.

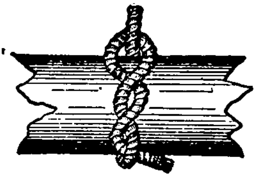
(19) *Rolling hitch*, used for hauling a larger rope or cable. Two turns are taken around the large rope in the direction in which it is to be hauled and one half hitch on the other side of the hauling part. A useful knot and quickly made. For armored cable or wet manila rope the hitch must be made with a strap of rope yarn. Rope will not hold.

(20) *Blackwall hitch*, used for attaching a single rope to a hook of a block for hoisting.

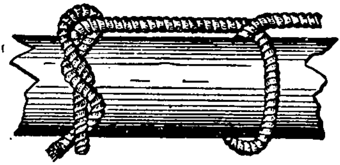
(21) *Mooring knot.*—Take two turns around the mooring or snubbing post, pass the free end of the rope under the standing part, take a third turn above the other, and pass the free end between the two upper turns.

(22) *Carrick bend*, much used for hawsers and to fasten guys to derricks.


Overhand
Figure of eight
Square or Reef
Granny
Thief
Single Sheet Bend
Double Sheet Bend
Clove hitch
Two half hitches
Round turn and two half hitches
Fisherman's Bend or Anchor knot
Clove hitch
①

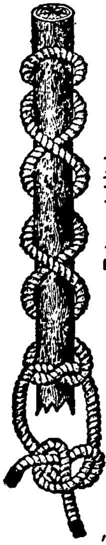


Timber hitch

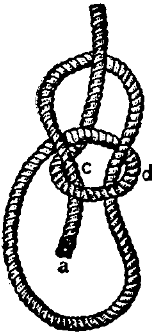


Timber hitch and Half hitch

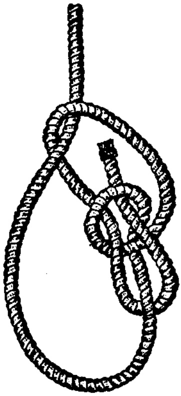
Hawser Bend



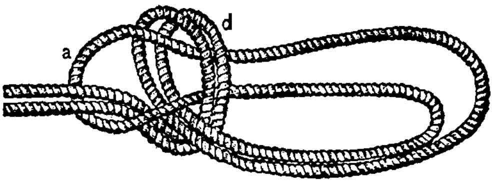
Telegraph hitch



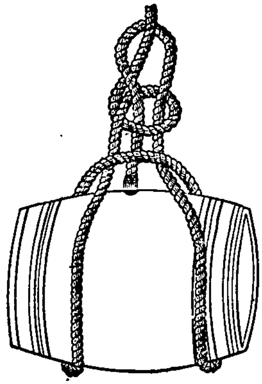
Bowline



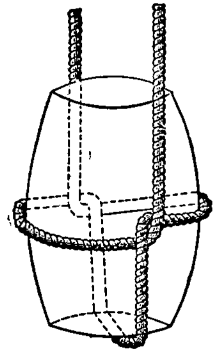
Running Bowline



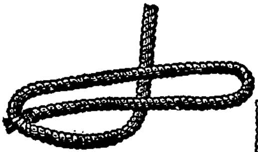
Bowline on a Bight



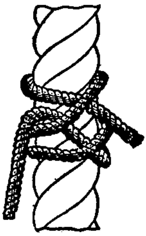
Sling for barrel horizontal



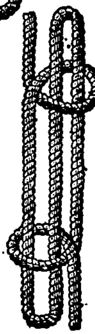
Sling for barrel vertical



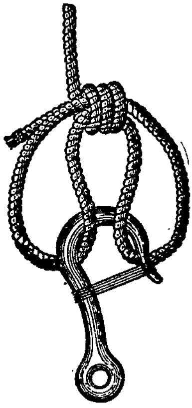
Cat's Paw a



Rolling Hitch



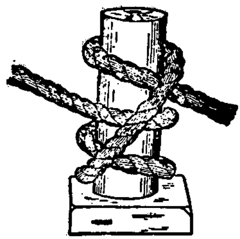
Sheepshank



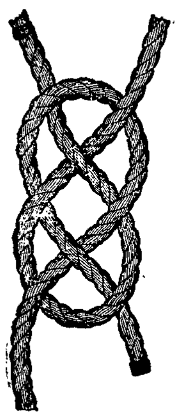
Cat's Paw b

③

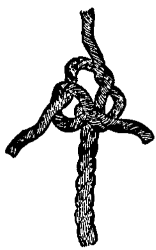
Blackwall Hitch



Mooring Knot

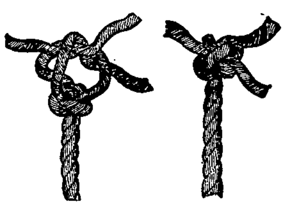


Carrick Bend



Wall Knot

Wall Knot



Crown on Wall

(23) *Wall knot and crown on wall;* both used for finishing off the ends of ropes to prevend unstranding.

b. Splices (see fig. 49).—(1) *Short splice.*—To make a short splice unlay the strands of each rope for a convenient length. Bring the rope ends together so that each strand of one rope lies between the two consecutive strands of the other rope. Draw the strands of the first rope along the second and grasp with one hand. Then work a free strand of the second rope over the nearest strand of the first rope and under the second strand, working in a direction opposite to the twist of the rope. The same operation applied to all the strands will give the result shown in Figure 49. The splicing may be continued in the same manner to any extent, and the free ends of the strands may be cut off when desired. The splice may be neatly tapered by cutting out a few fibers from each strand each time it is passed through the rope. Rolling under a board or the foot will make the splice compact.

(2) *Long splice.*—Unlay the strands of each rope for a convenient length and bring them together as for a short splice. Unlay to a desired length a strand, *a*, of one rope, laying in its place the nearest strand, *d*, of the other rope. Repeat the operation in the opposite direction with two other strands, *c* and *f*. Unlay half of strands *b* and *e*. Lay half of one in place of the unlayed half of the other. Pass the tops even through the rope. When the splice has been thoroughly stretched trim off the ends of the strands. This splice has the advantage of not enlarging the diameter of the rope at point of splice.

(3) *Eye splice.*—Unlay a convenient length of rope. Pass one loose strand under one strand of the rope, forming an eye of the proper size. Pass a second loose strand under the strand of the rope next to the strand which secures the first strand. Pass the third strand under the strand next to that which secures the second strand. Draw all taut and continue and complete as for a short splice.

97. Lashings.—*a. To lash a transom to an upright spar, transom in front of upright* (see fig. 50).—A clove hitch is made round the upright a few inches below the transom. The lashing is brought under the transom, up in front of it, horizontally behind the upright, down in front of the transom and back behind the upright at the level of the bottom of the transom and above the clove hitch. The following turns are kept outside the previous ones on one spar and inside on the other, not riding over

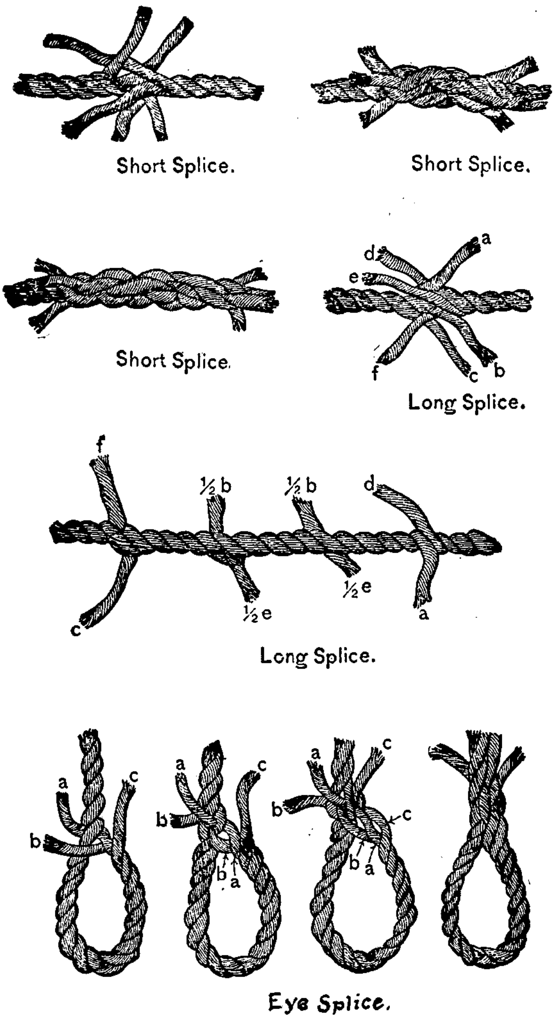


FIGURE 49.—Splices

the turns already made. Four turns or more are required. A couple of frapping turns are then taken between the spars, around the lashing, and the lashing is finished off either around one of the spars or any part of the lashing through which the rope can be passed. The final clove hitch should never be made around the spar on the side toward which the stress is to come, as it may jam and be difficult to remove. The lashing must be well beaten with handspike or pickhandle to tighten it up. This is called a square lashing.

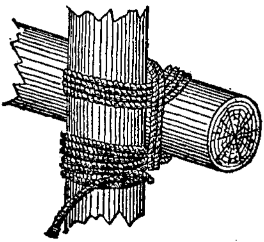


FIGURE 50.—Square lashing

b. Lashing for a pair of shears (see figs. 51 and 52).—The two spars for the shears are laid alongside of each other with their butts on the ground, the points below where the lashing is to be, resting on a skid. A clove hitch is made around one spar and the lashing taken loosely eight or nine times about the two spars above it without riding. A couple of frapping turns are then taken between the spars and the lashing is finished off with a clove hitch above the turns on one side of the spars. The butts of the spars are then opened out and a sling passed over the fork, to which the block is hooked or lashed, and fore and back guys are made fast with clove hitches to the bottom and top spars, respectively, just above the fork.

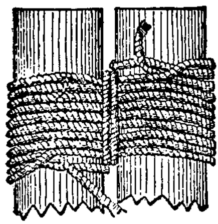


FIGURE 51.—Lashing for shears

c. To lash three spars together as for a gin or tripod (see fig. 53).—Mark on each spar the distance from the butt to the center of the lashing. Lay two of the spars parallel to each other with an interval a little greater than the diameter. Rest their tips on a skid and lay the third spar between them with its butt in the opposite direction so that the marks on the three spars will be in line. Make a clove hitch on one of the outer spars below the lashing and take eight or nine loose turns around the three. Take a couple of frapping turns between each pair of spars in succession and finish with a clove hitch on the central spar above the lashing. Pass a sling over the lashing and the tripod is ready for raising.

98. Holdfasts (see fig. 54).—*a.* To prepare a fastening in the ground for the attachment of guys or purchases, stout pickets

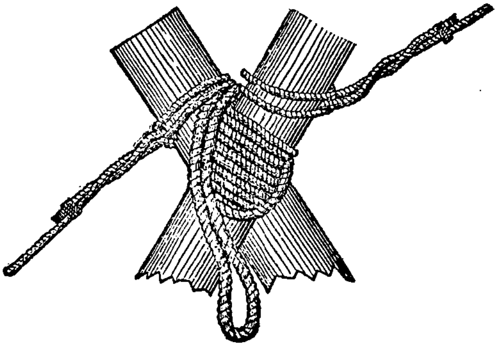


FIGURE 52.—Shears

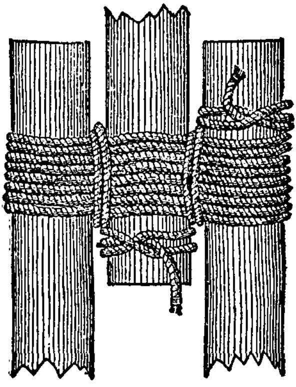


FIGURE 53.—Lashing for tripod

are driven into the ground one behind the other, in the line of pull. The head of each picket, except the last, is secured by a lashing to the foot of the picket next behind. The lashings are tightened by rack sticks, the points of which are driven into the ground to hold them in position. The distance between the

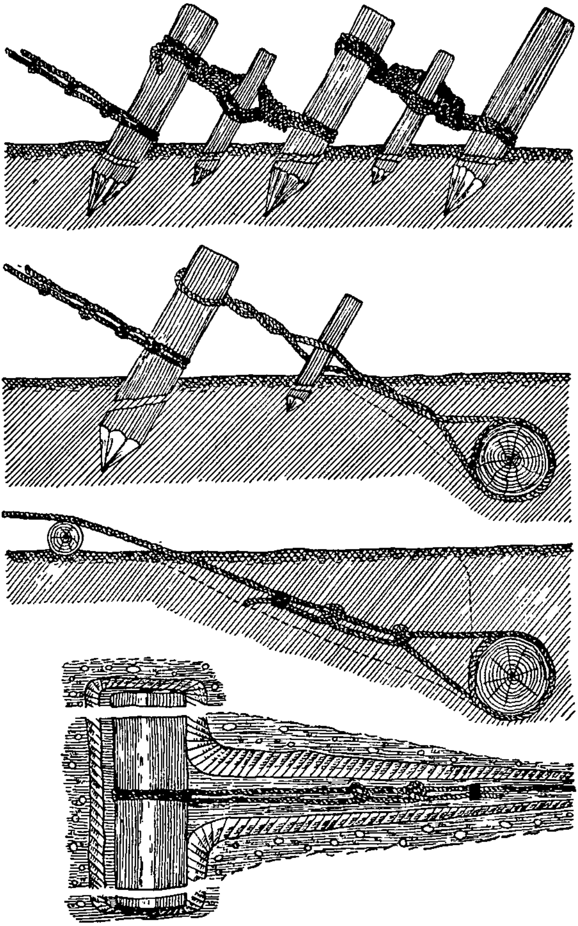


FIGURE 54.—Holdfasts

stakes should be several times the height of the stake above the ground. A single good ash picket, 3 inches in diameter, driven 5 feet into the earth, should stand a pull of about 700 pounds, except in very soft ground.

b. Another form requiring more labor but having much greater strength is called a "deadman," and consists of a log laid in a transverse trench with an inclined trench intersecting it at its middle point. The cable is passed down the inclined trench, takes several round turns on the log, and is fastened to it by half hitches and marline stopping. If the cable is to lead horizontally or incline downward, it should pass over a log at the outlet of the inclined trench. If the cable is to lead upward, this log is not necessary, but the anchor log must be buried deeper. The strength of the deadman depends upon the strength of the log and the holding power of the soil. The permissible pull on a round log deadman is given by the formula

$$P=\frac{1600\ d^3}{L}$$

Where P=pull in pounds.
d=diameter of log in inches.
L=length of log in inches.

The holding power of the soil is given in Table XXXIII.

99. Blocks and tackles (see fig. 55).—*a*. The parts of a block are the shell or frame, the sheave or wheel upon which the rope runs, and the pin upon which the wheel turns in the shell. A strap of iron or rope passes around the shell and forms attachments for a hook at one end and an eye at the other.

b. Blocks are also made entirely of metal, in which the strap is replaced by bolts. They are designated by the length of the shell in inches and by the number of their sheaves. Those with one, two, three, and four sheaves are called single, double, triple, and quadruple. The smallest size of block (length in inches) that will take a given rope is nine times the rope diameter. Self-lubricating blocks may be obtained and are to be preferred.

c. A *snatch block* is a single block with the shell and strap open at one side to admit a rope without passing the end through. A *running block* is attached to the object to be moved; a *standing block* is fixed to some permanent support. A *simple tackle* consists of one or more blocks rove with a single rope or fall. The spars in end of the fall fixed in the tackle is called the *standing end*, the other is the *running end.* Each part of the fall between the two blocks, or between either end and the block, is called a *return.*

d. To overhaul is to separate the blocks; *to round in*, to bring them closer together. When the blocks are in contact the tackle is said to be *chockablock.*

e. Blocks are used to change the direction of ropes and to give mechanical advantage or increase of pull. A man of average weight will pull about 60 pounds horizontally.

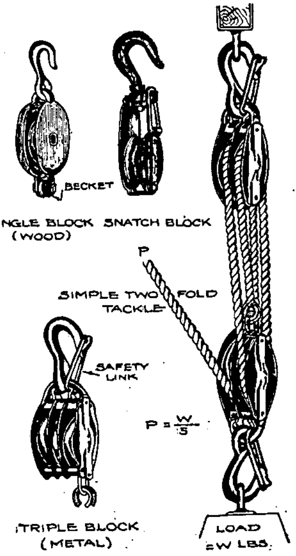


FIGURE 55.—Blocks and tackle

100. Slings.—Slings may be made of wire rope, hemp rope, or chain. The most commonly used sling is the cord-rope sling, usually made by splicing the two ends of the rope together. To use the sling, pass it around the article to be lifted. Pass the bight formed by one end through the bight formed by the other and then over the lifting hook. Slings of the same rope as the lifting rope should have a minimum angle of 30° made by the inclined portions with the horizontal. At this angle, the stress in the lifting rope is equal to the stress in the two branches of the sling. For angles greater than 30°, the load is limited by the lifting rope; and for angles less than 30°, the load is limited by the sling, assuming the lifting rope and sling to be of the same size rope.

101. Gin pole or standing derrick.—The gin pole (see fig. 56) is a single spar with the butt on the ground and the tip held securely by four guys at right angles to each other. The tackle is either lashed to the spar or suspended by a sling run through a slot in the head of the pole. Locate the foot of the gin pole. Lay a line through the point to mark the position of the fore and back guys. Lay another line at right angles to this. Mark the right and left guys. Lay off on the four lines distances equal to twice the length of the spar for level ground plus necessary slope allowances. Erect holdfasts at these points. Make the four guys fast to the top of the spar. Lay the spar along one of the guy lines with the butt nearly in the footing. Fasten a footrope to the butt and to a holdfast on the same side of the footing as the spar. Raise the top as high as possible by hand. Haul in the

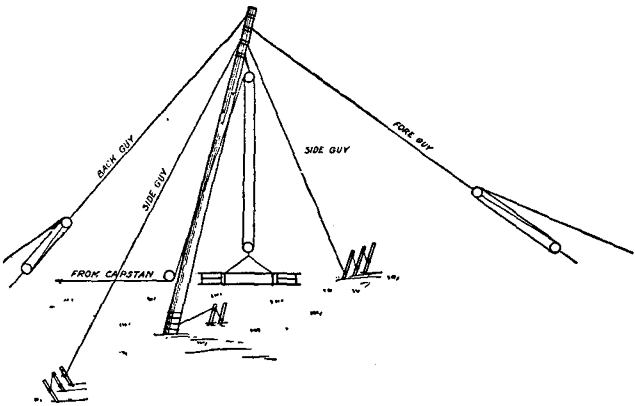


FIGURE 56.—Gin pole

back guy with a running tackle. Let the fore guy out. Take up all the slack on side guys. Continue this until spar is pulled into position, keeping all slack out of the guys. For heavy poles it is necessary to construct a light gin pole or shears first and to use this to raise the heavy pole. A hole should be dug to a depth of about 1 foot in hard ground. In soft ground it should be placed in a dugout with wooden supports laid in to transmit the ground pressure over a larger area.

TABLE XXXIII.—*Holding power of loamy earth*

Mean depth of a piece of anchorage below surface	Declination of drawing force (vertical to horizontal) and corresponding safe resistance to anchor pull in lbs. per sq. ft. of anchor face				
	Vertical	1/1	1/2	1/3	1/4
1 foot	70	110	150	160	175
1 foot 6 inches	150	250	320	360	390
2 feet	290	410	580	650	700
3 feet	600	950	1,300	1,450	1,500
4 feet	1,050	1,750	2,100	2,600	2,700
5 feet	1,700	2,800	3,600	4,000	4,100
6 feet	2,400	3,800	5,100	5,800	6,000
7 feet	3,200	5,100	7,000	8,000	8,400

For wet earth the holding power should be multiplied by the following factors:

Hard gravel 0.9
River clay 5
River sand 5

TABLE XXXIV.—*Strength of chains*

Size of chain, diameter of steel	Open link safe load	Stud link safe load
Inches	*Pounds*	*Pounds*
½	2,000	2,500
⅝	3,125	3,900
¾	4,500	5,625
⅞	6,125	7,656
1	8,000	10,000
1¼	12,500	15,000
1½	18,000	22,500

TABLE XXXV.—*Strength of hooks*

Size of rounds	Safe strain
Inches	*Pounds*
⅝	250
1/16	500
¾	1,000
1 1/16	2,000
1¼	3,000
1⅜	4,000

TABLE XXXVI.—*Simple block and tackle rigging manila rope (factor of safety 3)*

Load to be lifted	Total number of sheaves in blocks	2 (2 single blocks)	3 (1 single 1 double)	4 (2 double blocks)	5 (1 double 1 triple)	6 (2 triple blocks)
Tons						
½	Smallest permissible rope diameter (inch)	½	7/16	⅜	⅜	⅜
	Lead line pull, in pounds	540	380	300	250	220
1	Rope (inch)	¾	⅝	½	½	½
	Pull	1, 100	760	600	500	440
1½	Rope (inch)	⅞	¾	⅝	⅝	½
	Pull	1, 600	1, 100	900	750	660
2	Rope (inches)	1⅛	⅞	¾	⅝	⅝
	Pull	2, 200	1, 500	1, 200	1, 000	880
3	Rope (inches)	1 5/16	1⅛	1	⅞	¾
	Pull	3, 300	2, 300	1, 800	1, 500	1, 300
4	Rope (inches)	1½	1¼	1⅛	1	1
	Pull	4, 400	3, 000	2, 400	2, 000	1, 800
6	Rope (inches)	--------	1½	1 5/16	1¼	1⅛
	Pull	--------	4, 500	3, 600	3, 000	2, 600
8	Rope (inches)	--------	--------	1⅝	1½	1 5/16
	Pull	--------	--------	4, 800	4, 000	3, 500

102. Line and grade.—In order that the bridge will be in a correct position and at the proper elevation, it is necessary to give line and grade, by suitable reference marks, to the workmen. Time spent in accurately placing stakes and other references for this purpose saves time in the construction. The center line of the bridge should be indicated by range poles on the shore. By sighting on these range poles, intermediate points may be located. A stake should be driven in the center of the approach roadway about 3 feet from the position of the proposed abutment. Other stakes should be driven marking the location of the center of each bent. If the water prevents the placing of these stakes, line may be indicated by a string or tape stretched across the gap. In order that this tape may not interfere with the workmen, it should be placed a given distance to the right or left of the center line of the bridge. The grade or elevation of the cap at each bent may be given by an instrument man on shore using a hand or other level. The size of the bents is determined by the data obtained on a reconnaissance of the bridge site, but in practice the actual height of the cap will seldom fall exactly at the desired grade. It may therefore be necessary to modify the position of the cap or to shim up under the stringers in order that the roadway crossing the bridge will be tolerably even.

103. Organization of the working party.—The available workmen are organized for the erection of the bridge as follows: One party for the preparation and construction of the abutment; one party for the preparation of the approaches; one party for the procurement of materials, if necessary; one party for the framing of the bents; one or more parties for the erection of the bents; one or more parties for the placing of stringers; one party for the placing of flooring and side rails; one party for placing sway bracing; one party to attend to the details of line and grade. The size of the parties depends upon local conditions, but should be modified as the work progresses so that the work of the entire construction will proceed efficiently.

TABLE XXXVII.—*Properties of wire rope*

Nominal diameter	Approximate circumference	Approximate weight per foot	Breaking strength	Maximum safe working load. Factor of safety=5	Recommended minimum diameter of sheave or drum
Hoisting ropes, cast steel, 6 strands of 19 wires each, not galvanized					
Inches	*Inches*	*Pounds*	*Pounds*	*Pounds*	*Feet*
¼	¾	0. 10	4, 200	840	1. 0
5/16	1	. 15	6, 400	1, 280	1. 2
⅜	1⅛	. 22	9, 000	1, 800	1. 5
7/16	1¼	. 30	12, 000	2, 400	1. 8
½	1½	. 39	15, 400	3, 080	2. 0
9/16	1¾	. 50	19, 200	3, 840	2. 2
⅝	2	. 62	23, 600	4, 720	2. 5
¾	2¼	. 89	33, 600	6, 720	3. 0
⅞	2¾	1. 20	45, 600	9, 120	3. 5
1	3	1. 58	59, 000	11, 800	4. 0
1⅛	3½	2. 00	74, 000	14, 800	4. 5
Standing or guy ropes, cast steel, 6 strands of 7 wires each, galvanized					
5/16	1	0. 150	5, 600	1, 120	----------
⅜	1⅛	. 220	7, 800	1, 560	----------
7/16	1¼	. 300	10, 600	2, 120	----------
½	1½	. 390	13, 600	2, 720	----------
9/16	1¾	. 500	17, 000	3, 400	----------
⅝	2	. 62	20, 800	4, 160	----------
¾	2¼	. 89	29, 600	5, 920	----------
⅞	2¾	1. 20	40, 000	8, 000	----------
1	3	1. 58	52, 200	10, 440	----------
1⅛	3½	2. 03	65, 600	13, 120	----------

This table gives strength values for wire ropes of cast steel. The strength of wire ropes of other material may be found by multiplying the values given by the following factors:

Phosphor bronze	0. 50
Iron	. 50
Extra strong cast steel	1. 10
Plow steel	1. 20
High-grade plow steel	1. 50

The strength of galvanized wire rope is about 10 per cent less than that of ungalvanized rope of same size.

If the diameter of the drum or sheave is less than the recommended diameter, lower safe working loads should be used.

TABLE XXXVIII.—*Properties of 3-strand Manila rope, medium lay*

[Federal specifications]

Circumference	Diameter (nominal)	Length of coil (approximate)	Gross weight of coil (approximate)	Weight per foot (maximum)	Length per pound (minimum)	Breaking strength (minimum)
Inches	*Inches*	*Feet*	*Pounds*	*Pounds*	*Feet*	*Pounds*
½	3/16 (6 yarns)	3, 000	45	0. 011	90. 9	590
¾	¼ (6 yarns)	2, 750	55	. 020	50. 0	700
1	5/16 (9 yarns)	2, 250	65	. 033	30. 3	1, 200
1⅛	⅜ (12 yarns)	1, 620	66	. 041	24. 4	1, 450
1¼	7/16 (15 yarns)	1, 200	70	. 050	20. 0	1, 750
1½	½ (21 yarns)	1, 200	90	. 070	14. 3	2, 450
1¾	9/16	1, 200	126	. 094	10. 6	3, 150
2	⅝	1, 200	160	. 122	8. 20	4, 000
2¼	¾	1, 200	198	. 152	6. 58	4, 900
2½	13/16	1, 200	234	. 188	5. 32	5, 900
2¾	⅞	1, 200	270	. 226	4. 42	7, 000
3	1	1, 200	324	. 268	3. 73	8, 200
3¼	1 1/16	1, 200	378	. 314	3. 18	9, 500
3½	1⅛	1, 200	432	. 363	2. 76	11, 000
3¾	1¼	1, 200	504	. 412	2. 43	12, 500

104. Tools.—The tools used in bridge construction are crosscut saws for framing bents, augers for boring holes for driftbolts, sledge hammers for driving driftbolts, foot adzes for dapping where necessary, hammers for spiking, wrenches for tightening nuts on bolts, pinch bars and peavies for moving timber. A skiff is used when working in a water gap. Kapok footbridge equipage and ponton equipage are useful for this purpose.

105. Erection of simple stringer bridges.—Excavate the approaches to provide firm footing for the bank seats. Place the bank seats, using sufficient layers of footing planks to give the required elevation. Place the end dam. The stringers may be placed in position by hand or by the use of a gin pole or A frame. Lay and spike the floor planks. Place and bolt curb and handrail. Tamp the earth firmly behind the end dam.

106. Erection of trestle bridges.—*a. Erection in the dry.*—If the crossing is dry or the water is shallow enough so that trestles may be snaked into place by hand or by animals, the

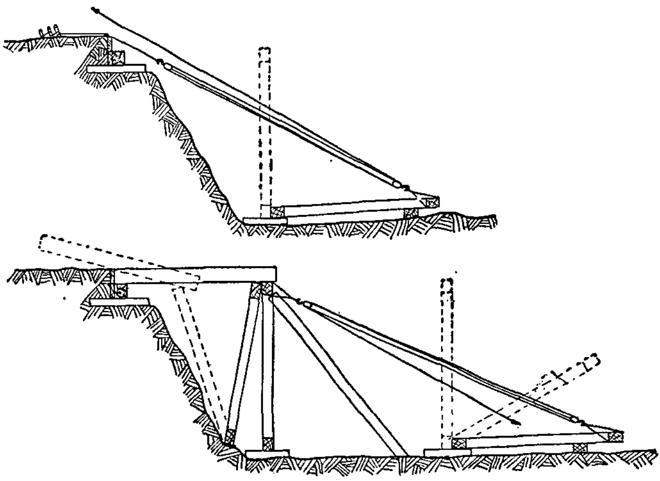


FIGURE 57.—Erection of trestle bridge

simplest method of construction is to erect the trestles on the mudsills by means of tackle as indicated in Figure 57. The ground is prepared for the mudsills while the bents are being framed.

b. Erection in the wet.—One method of erection in water is to place sloping skids from the completed portion of the bridge to the bed of the stream at a point about a foot beyond the final location of the bent. Footropes are attached to the lower part of the bent so that it can be pulled back to its final position after it is slid down the skids and pushed to an upright position by means of pike poles. It is in most cases difficult to spot the bent exactly in its proper position from the skids and it is therefore better to place it a little too far out and then draw it back than to have it too close and be obliged to push it further out. In deep water it may be necessary to overcome the flotation of the bent by boarding it up at the bottom so as to form a pocket between the posts into which rock or other ballast is put. Where necessary to use mudsills they may be rafted together and sunk by placing stones on the outer ends of the sills clear of the place where the bent is to rest.

c. Placing stringers.—After each bent is erected, the stringers may be placed in position by means of a gin pole or an **A** frame or by the use of a balance beam. To use the gin pole, erect the pole halfway between two bents, attach the raising rope to the center of the stringer to be raised. Attach a rope to each end of the stringer to guide it into place. Raise the stringer and lower it in place, guiding it by means of guide ropes. All of the stringers may be placed in position in this manner, but it is often simpler to raise but two stringers by this method and place the rest by rolling them on dollies or rollers made of iron pipe across these two stringers, shifting them into position with timber hooks or peavies after they have been rolled out.

d. Erection with crane.—If a truck crane is available the erection of a trestle bridge can be greatly expedited. The bents are framed on the shore near the bridge site. The truck crane picks up an entire bent by the cap and proceeding out over the completed portion of the bridge lowers the bent into place. The stringers may be similarly placed.

107. Erection of pile bridges.—*a. Pile driving, various methods.*—The three methods commonly used are—

The drop hammer.
The steam or air hammer.
The water jet.

The water jet may also be used to facilitate driving by the other methods. In addition screw piles are sometimes used where only a light bearing value is needed.

b. Driving piles with drop hammer pile drivers.—The piles should be raised in the leads by means of a separate line rove through a separate sheave on the top of the driver and wound either on a drum or about a spool or winch head attached to the engine. Piles should be held in place between the leads by means of wooden levers and the hammer lowered on top of the pile and allowed to rest there for a moment to see that everything is lined up and so that the hammer will strike squarely. The drop should be short, about one or two feet, for the first three or four blows, increasing in length as the driving progresses. As speed is a prime requisite in military operations, the fall of the hammer should be increased to the maximum as soon as possible. It is difficult to give written directions on exactly how to handle the hammer as the behavior of the piles under the blow has much to do with it. For instance, it might be possible to drive a pile into a hard stratum by a short fall of the hammer where a long fall might possibly break it. It is a question for judgment in any particular case. All the piles in one bent are driven in succession proceeding from one side to the other.

c. Driving piles with water jet.—This method has the great advantage that the pile is not subject to damage from the blows of the hammer. It is a very rapid and effective method in sand or fine gravel. In fact it is often difficult to drive piles in sand by the drop-hammer method, while in ordinary earth or clay the water-jet method is useless. The water jet requires a powerful pump and an adequate supply of hose and pipe. For ordinary piles a pipe may be clamped or stapled to the side of the pile with its lower opening at the bottom of the pile, or the pipe may be supported by a separate line and slipped down alongside the pile without being attached to it. The top of the pipe is near the top of the pile. It is connected by means of a flexible hose with the delivery pipe of the pump. The pile is raised in position and held there as described for ordinary driving either between the leads of an ordinary pile driver, if such is available, or by guys. The best work can be done with a pump having a capacity of about 250 gallons per minute, at a pressure of about 100 pounds per square inch, pumping through a 1½-inch pipe attached to the pile. The action of the water jet is to loosen the material at the point of the pile; it then sinks because of its own weight, and any additional weight that can be placed upon it. If a drop hammer pile driver is available, the hammer should rest upon the pile. A few blows of the hammer will materially expedite the rate of sinking. When the pile has been sunk to within 2 or 3 inches of its final depth, the pump is stopped and the pipe is withdrawn.

d. Mounting equipment.—In building a pile bridge of any considerable length over a large water gap time can be saved by placing the pile driving equipment on a barge or scow. This is particularly true when a two-way bridge is being erected. If no barge or scow is available and the driver must rest on the bridge, time will be saved by constructing two one-way bridges rather than one two-way bridge.

e. Determination of point when driving shall cease.—(1) Piles should always be driven at least 8 feet to secure sufficient penetration for stiffness. The remaining distance necessary to give the pile a certain bearing power can be determined by noting the penetration at frequent intervals and, from these data, calculating the bearing power of the pile by the formula given in paragraph 61.

(2) For the water jet, the bearing power of the pile can be determined somewhat by a study of the material through which the pile is driven. If the data obtained from study are insufficient, a test must be made by building a platform on a test pile or piles and loading the platform with sandbags or other heavy material until observation over a period of time shows the pile to be sinking. One-third of this load may be taken as the safe bearing value of the bridge.

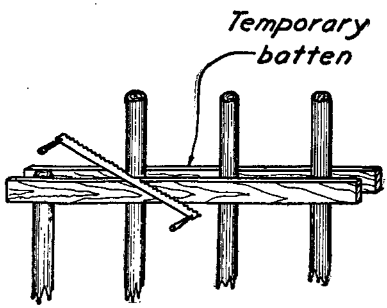


FIGURE 58.—Framing pile bent

f. Framing pile bents.—Piles should be sawed off at the proper elevation exactly level. (See fig. 58.) The cap is then driftbolted to the piles and the stringers placed. Often the driver may be used as a derrick to place the caps and stringers. The driver is then moved forward to drive the next bent.

108. Crib construction.—In dry situations cribs are built on the site. Cribs for use in water may be built on shore on inclined ways and when up to a sufficient height to form a substantial raft may be launched and floated to their places. The sinking ballast is then placed in the closed compartments or on the floor prepared to receive it, until the crib is well grounded. By means of spars set in the corners with tackle attached the lower corners may be raised until the crib is level, and the rest of the ballast thrown in.

109. Erection of demountable steel highway bridges.—Figure 59 shows a suggested method of erecting the demountable steel highway bridge. The truss is assembled and bolted on the river bank with its axis lying in the direction of the bridge. It is launched forward on rollers and carried across the chasm by means of the tackle as shown. The essential equipment for this method includes a gin pole, winch, hauling tackle, back anchorage on the far bank and launching rollers, preventer tackle and winch, gin pole and anchorage on the near bank. The truss is hauled into position by taking up on the hauling tackle and simultaneously paying out on the preventer tackle. When the truss has passed the center point it should be allowed to dip about one-tenth of the span in order to lessen the stresses in the tackle and to assist the launching. As the end of the truss approaches the far bank the hauling tackle is taken in so as to raise the truss to a horizontal position. The auxiliary gin pole is then brought into use to raise the end of the truss on the near bank off the rollers and, by heeling over the auxiliary gin pole, the truss is brought into a position with its ends vertically over the bank seats. It is then lowered into place. Figure 60 illustrates a graphical method of determining the stresses in the tackle for any position of the truss. The remaining trusses of the span are placed in similar manner or with the aid of the trusses already in place. The flooring is then applied and fastened. Other methods suggested for the erection of spans of this type include floating the span into position upon a barge and the erection of the span on a light false work.

110. Erection of wooden trusses.—Wooden trusses of the type shown are erected on a scaffolding or false work which is first constructed in the chasm. The false work is ordinarily some form of trestle or crib construction. The road bearers are first placed in their positions at the panel points. The lower chords are then laid on top of the road bearers and with their ends in place on the abutments. The top chords are then raised on temporary supports footing on the false work to positions a few inches above their final ones so that the web members may be slipped into place. The top chord is then lowered until its weight comes on the diagonals. The nuts are then tightened on the tension rods working uniformly along the entire truss, until the desired camber is developed and the middle of the truss rises, leaving its weight entirely on the abutments. The stringers and flooring are then applied.

111. Erection of suspension bridges.—First lay out the line of the bridge passing a rope with a traveling block across the

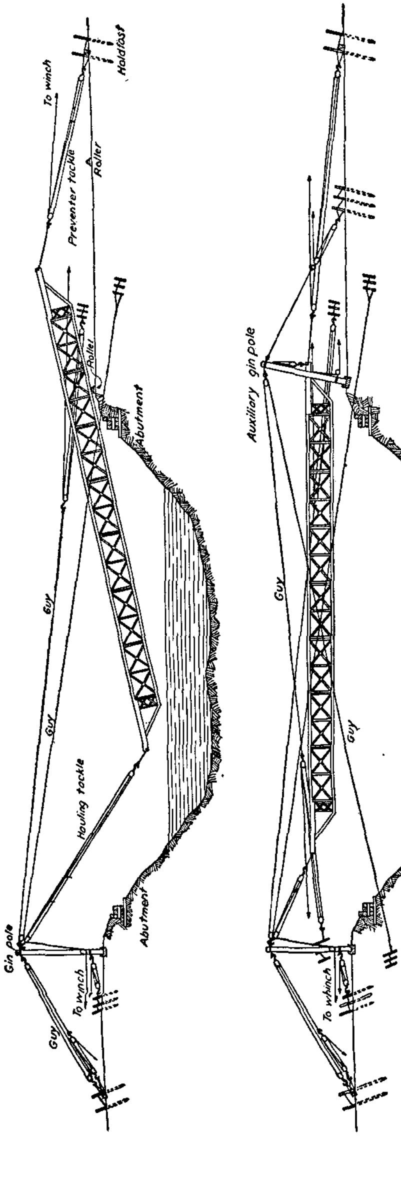


FIGURE 59.—Erection of demountable steel highway bridge

chasm or gap to use in carrying cable ends across the gap. Towers may be constructed on the ground and raised in place by means of a gin pole. The cable first is permanently fastened at one anchorage. The bight is raised until it rests on the saddles on the tops of the towers and the cable is then adjusted to the proper dip by hauling at the other end with a tackle. When the adjustment of the dip is finished the remaining end of the cable is made permanently fast to the anchorages and the tackle removed. When both cables have been placed the roadway is constructed by hanging a road bearer to each pair of slings. The stringers are then placed as in ordinary stringer bridges. The stringers should be long enough to lap several feet and should be permanently lashed or spiked together. The lap need not

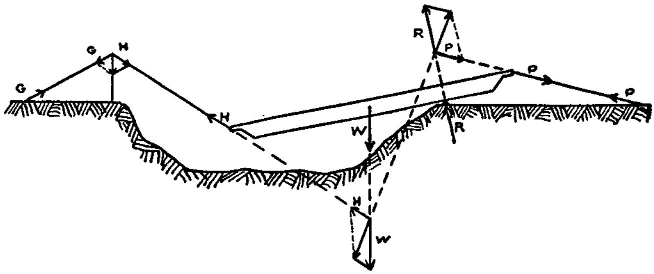


FIGURE 60.—Graphical determination stresses in tackle

be on a road bearer, but it is better near one. The floor planks are then placed on the stringers and spiked down or held by the guard rail.

SECTION V

FLOATING BRIDGES

112. Types of ponton equipage.—The four types of ponton equipage in use are the light equipage, M1926; the heavy equipage, M1869; the light canvas equipage and the heavy equipage, M1924. The light equipage, M1926, and the heavy equipage, M1869, are very similar to each other and in future operations will serve exactly the same purposes, that is, tactical ponton bridge operations with infantry or cavalry divisions. The light canvas type is obsolescent since it is not adaptable to passing motor loads greater than ½-ton trucks. The heavy equipage, *M1924, is the only* equipage that has been developed to transport the heaviest loads accompanying the Army in the field. All types have a width of roadway suitable for a single column of vehicular traffic and all are somewhat similar to each other as to their principal component parts; abutments, trestle spans for nonfloating portions of the bridge and ponton spans for the floating portions. In all types some form of flexible joint (called a saddle or hinge) is provided where trestle spans join the ponton spans in order to care for fluctuations of the floor level, due to the rise and fall of tide or floods, and the submergence of the ponton span under passing loads. The floor system in all types is formed by stringers (called balks) running between the ponton or trestle supports, upon which floor planks (called chess) are laid. The chess are held down by side rails which serve also to keep traffic from going off the roadway. The alignment of the bridge is maintained by anchors attached to the pontons.

113. Capacity of ponton bridge equipage.—*a. Light equipage, M1926.*—The maximum safe load for this bridge is a gross load of 16,000 pounds per bay with a maximum single axle load of 10,000 pounds and at least 9 feet between axles. This includes light tanks, 3-ton trucks loaded, and 5-ton trucks carrying not more than 2 tons. A continuous column of traffic is permissible, but speed should be restricted to 5 miles per hour and a minimum distance of 16 feet should be maintained between vehicles. Tests indicate that the bridge is unsafe regardless of, reinforcement for loaded 5-ton trucks and for 155-mm. guns. While the strength of this bridge can be increased by increasing the number of balks per bay or by adding trestles to trestle bays and pontons to ponton bays, thus shortening the span, such reinforcement is not recommended, since it complicates the construction and is wasteful of equipment and time. The ferrying capacity of each ponton of this equipage is 25 fully equipped riflemen in addition to the crew of 5.

b. Heavy equipage, M1869.—With normal construction (5 balks per bay) this bridge has a capacity of 4,600 pounds gross load with a maximum single axle load of 3,000 pounds and at least 11 feet between axles. This includes all animal-drawn transportation including the 75-mm. gun, light passenger cars, ½-ton trucks loaded, ¾-ton trucks partially loaded, heavy passenger cars empty, and 1-ton trucks empty. When reinforced by the addition of two balks per bay it has a maximum capacity of 8,000 pounds with a maximum single axle load of 4,000 pounds and axles at least 11 feet apart. This includes loaded 1-ton trucks and partially loaded 1½–2 ton trucks. A continuous stream of traffic is permissible, but speed should be restricted to 2 miles per hour and a minimum distance of 20 feet should be maintained between vehicles. The ferrying capacity of each ponton of this equipage is 30 fully equipped riflemen plus the crew of 5. In rough water or swift currents 20 riflemen and the crew make a suitable load.

c. Heavy equipage, M1924.—This equipage is capable of carrying the maximum vehicular loads accompanying a field army. This includes the 23-ton tank and maximum axle loads of 25,000 pounds. A continuous stream of traffic is permissible, but a minimum distance of 32 feet should be maintained between vehicles and speed should be restricted to 5 miles per hour. The ferrying capacity of each ponton is 57 fully equipped riflemen plus the crew of 7.

d. Light canvas equipage.—With normal construction (5 balks per bay) this equipage will pass all animal-drawn transport including the 75-mm. gun. The same restrictions as to speed and interval between vehicles should be maintained as on the heavy equipage, M1869. The ferrying capacity of each ponton is 20 fully equipped riflemen plus the crew of 5.

114. Light ponton equipage, M1926.—*a. Pontons.*—The ponton has an over-all length of 26 feet 6 inches, beam 5 feet at the gunwale, 4 feet 10½ inches at the bottom, and a depth of 2 feet 7½ inches at the middle section. The ponton is symmetrical as to bow and stern. The frames are of duraluminum. The skin of the ponton is of aluminum. Its displacement is as follows:

Submergence	Water displaced	Freeboard
Inches	*Pounds*	*Inches*
6	3,280	24
12	6,837	18
15	8,685	15
18	10,576	12
21	12,509	9
24	14,481	6

A locker is provided at bow and stern for storing ponton equipment. A mooring windlass is provided at each end for maneuvering the boat into position and for alignment when in the bridge. Ten rowlock sockets are at convenient points along the gunwale. The floor of the boat consists of a wooden grating. The ponton weighs approximately 1,200 pounds and can be handled by one noncommissioned officer and ten men. The boat is rowed when light and under normal conditions by means of four 12-foot oars and is steered by a fifth oar.

b. Trestles.—The trestle consists of 7 separable parts—1 transom, 2 columns, 2 chain hoists, and 2 trestle shoes. The weight of the trestle complete is approximately 1,150 pounds. The transom is adjustable and is raised and lowered by means of a chain hoist on its two end supporting columns which stand on shoes which allow the columns to remain in a vertical position even when the shoes rest upon a sloping bottom. The transom is supported in place at any desired height by means of pins that pass through the end plates of the transom and corresponding holes in the columns. The columns are made of 4½-inch diameter steel tubing and stand 15 feet 4 inches high. The chain hoists are standard commercial 1-ton chain hoists. The trestle will carry 15 tons.

c. Floor system.—The floor system of each span consists of 7 balks, 2 side rails, and 16 chess. The side rails of all spans are laid on top of the chess and fastened by means of lashings and rack sticks. The clear width of roadway is 10 feet.

d. Hinge.—The last trestle span is connected to the first ponton span of the bridge by a hinge. (See fig. 62.) The hinge sill is normally located at some convenient point between the first and second ponton, and is suspended by means of hinge sill hangers from each balk of the first ponton span. The trestle ends of the balks rest on the transom of the trestle, the river ends rest free on the hinge sill in a manner which allows the balks to adjust themselves to changes in the gradient of the roadway.

e. Ponton balks.—The ponton balks are of wood, 6 inches by 4 inches by 21 feet 5 inches, weighing about 130 pounds, and are easily handled by two men. They are used in ponton and hinge spans as roadway bearers and side rails giving a span of 16 feet, center to center, of pontons. They are fastened to the gunwales of the pontons by rigid metal balk fasteners which are tightened by a turnbuckle. Steel balks may be provided in lieu of wood.

f. Trestle balks.—Trestle balks are of wood, 6 inches by 4 inches by 16 feet 3½ inches, weighing 96 pounds. They are used in trestle and abutment spans as roadway bearers and side rails giving a span of 16 feet. They are fastened to the transom of the trestles by lashings, but rest free on the abutment sill.

g. Chess.—The chess are of wood, 11⅞ inches by 2⅛ inches by 12 feet, weighing 60 to 80 pounds.

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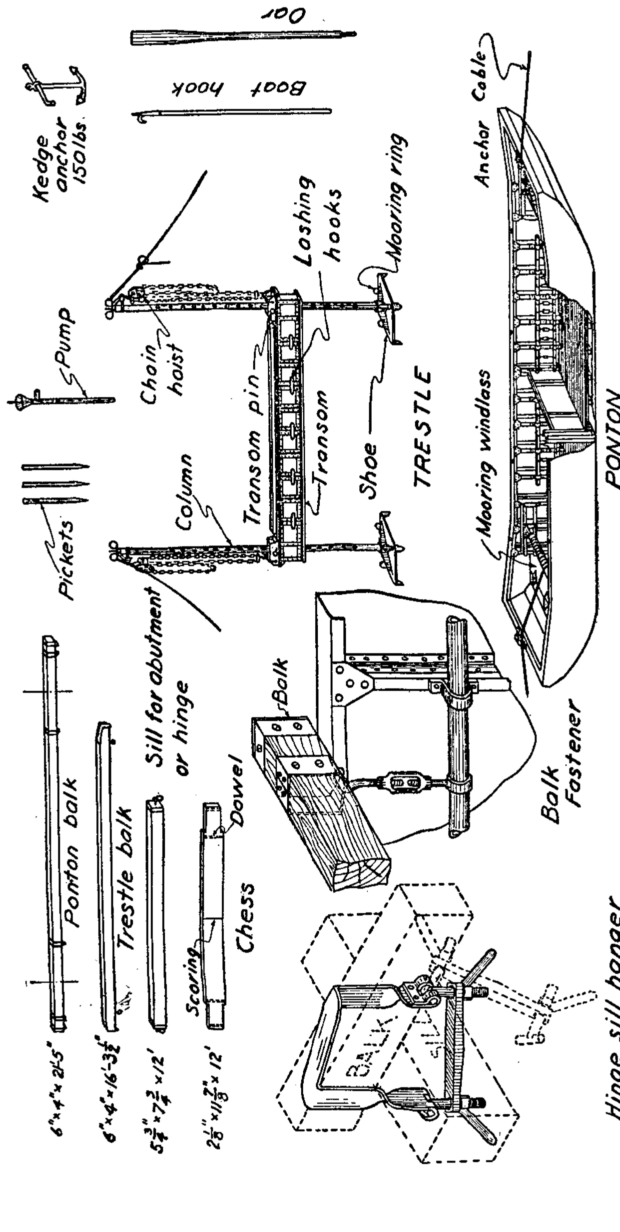


FIGURE 61.—Light ponton equipage, M1926

h. Sills.—The abutment sill and hinge sill are exactly alike and are of wood, 5¾ inches by 7¾ inches by 12 feet.

i. Hinge sill hangers.—Hinge sill hangers are of metal and are used to support the hinge sill underneath the balk of the first ponton span.

j. Miscellaneous items.—The *anchors* are 150-pound kedge anchors. The *anchor cables* are of manila rope 1 inch in diameter, 240 feet long. *Manila rope lashings* ½ inch in diameter by 18 feet long are used to lash the trestle balks to the trestle transom and for replacing unserviceable balk fasteners. Each ponton is equipped with seven *oars*, a sheet steel *pump* for bailing out water, *oar locks*, and a ball pointed *boat hook.*

k. Transportation.—The equipage is transported on special vehicles which are adapted to animal or motor traction. Each vehicle is equipped with the necessary supporting and clamping devices to transport the three types of loads as follows:

(1) *Load for ponton span.*—One ponton, 9 ponton balks, 16 chess, and miscellaneous items including anchors, anchor buoys, anchor cables, oars, boat hooks, windlass sticks, pump, rack sticks, and lashings.

(2) *Load for trestle span.*—One trestle transom, 2 columns, 9 trestle balks, 2 shoes, 16 chess, 2 chain hoists, and miscellaneous items including anchors, anchor buoys, anchor cables, lashings, windlass sticks, and rack sticks.

(3) *Load for abutment span.*—Four sills, 9 trestle balks, 16 chess, and miscellaneous items including pickets, hinge sill hangers, anchors, scales (20-ton) to measure vehicular loads, anchor cables, buoys, lashings, rack sticks and windlass sticks.

115. Heavy ponton equipage, M1869.—*a. Pontons.*—The ponton is of wood, 31 feet in length, with a maximum breadth of 5 feet 8 inches and a depth of 2 feet 8 inches at the middle section. Its displacement is as follows:

Submergence	Water displaced
Inches	*Pounds*
12	6,150
15	8,150
16	8,825
18	10,125
21	12,250
24	14,550
28	17,750

b. Trestles.—The trestle consists of a cap with pins, two legs with shoes and keys, and two wedges. The legs are inclined to give lateral stability. The cap is adjusted by means of two cap levers, one of which is carried on each trestle wagon.

c. Floor system.—The floor system with normal construction consists of five balks, two side rails, and the necessary chess. Additional balks may be used to give a reinforced construction. The side rails are laid on top of the chess and fastened by means of lashings and rack sticks. The clear width of roadway is 10 feet 2 inches.

d. Balks.—The balks are 5 by 5 inches in cross section. There are two kinds of balks used with the heavy equipage. The long balk is 27 feet long and is provided at each end with an oak cleat and a dowel hole. The clear distance between cleats is 25 feet 8 inches, giving a normal bay of 20 feet center to center of pontons. The bays between the pontons and the trestles are 22 feet 6½ inches from center of ponton to center of trestle cap. The trestle balk is 21 feet 8 inches long and is provided at each end with a dowel hole and two cleats forming a claw with an 8-inch opening. The distance from center to center of claws is 20 feet, giving a bay 20 feet long. The balks are also used for side rails. The balks are fastened to the gunwales of the pontons by rope lashings as shown in Figure 64.

e. Chess.—The chess is a plank, 13 feet by 12 inches by 1½ inches. The width at each end is reduced to 10½ inches for a distance of 2 feet, thus forming a notch on each side of the roadway for the passage of the side rail lashings. The middle line across each chess is marked on both sides with a fine saw cut.

f. Saddle transom.—The saddle transom is 5 feet 4 inches by 8 inches by 4 inches, with a strong steel hook at each end to fit over the gunwales of the pontons. There are two small cleats on the middle of the transom forming a recess 6¼ inches wide to receive a sill.

g. Sills.—The sill is 14 feet by 8 inches by 6 inches, scored to mark the position of the balks. For ease in handling it is provided with a ring in each end. The same sill is used either as an abutment or as a saddle.

h. Miscellaneous items.—The *anchor* is of the kedge type weighing 150 pounds. The *boat hook* is of the ordinary form, 10 feet in length. The *bucket* is the ordinary galvanized iron bucket. The *cable* is a 3-inch circumference manila rope, 240 feet in length. *The balk and side rail lashings* are of 1-inch circumference manila rope, 18 feet in length, whipped at one end, with an eye-splice at the other. The *oar* is of the ordinary form 14 feet in length. The *picket* is of oak or hickory, 3 feet long and 3 inches in diameter, protected at both ends with steel. The *pump* is of galvanized sheet steel. The *rack collar* is of strap steel made in two parts united by a link on each side. The inside measurement of the collar is 1 foot 7 inches by 5 inches. Folding oak wedges are used with rack collars. The *rack stick* is of hickory 2 feet long and 1¼ inches in diameter.

i. Transportation.—The equipage is carried on three types of wagons—ponton wagons, chess wagons, and ponton tool wagons. The ponton wagon differs from the chess wagon only in being of heavier construction and having longer side rails and in the form of standards for securing the load. The ponton tool wagon is of special construction. The ponton wagon is drawn by six mules, the other wagons are drawn by four mules. This kind of transportation is not adaptable to motor traction, but may be so drawn at low speeds, care being taken to keep the axles properly lubricated. The loads are as follows:

(1) *Ponton wagon load:*

1 ponton.
7 long balks.
1 anchor.
1 cable.
5 oars.
2 boat hooks.
20 lashings.
6 rack sticks.
1 boom.
1 axe.
1 hatchet.
1 picket.
9 rowlocks.
20 pounds marline.
5 pounds axle grease.
1 spare tongue.
1 spare singletree.

(2) *Trestle wagon load* (same chassis as ponton wagon):

7 long balks.
7 trestle balks.
1 trestle, complete.
1 cap lever.
8 pickets.
2 sills.
2 saddle transoms.
2 halfcoils of 3-inch circumference rope, 720 feet each.
1 spare tongue.
1 picket.
1 axe.
1 spare singletree.

(3) *Chess wagon load:*

60 chess.
1 picket.
1 axe.

(4) *Ponton tool wagon load:*

1 set of blacksmith's equipment.

1 set saddler's equipment.

Miscellaneous supplies and spare parts.

116. Heavy ponton equipage, M1924.—*a. Pontons.*—The ponton is a wooden boat of the scow type. The over-all length is 32 feet, over-all width 6 feet 6 inches, and the over-all height at mid-section, including the skids, 3 feet 5 inches. The displacement of the ponton is as follows:

Submergence	Water displaced	Freeboard
Inches	*Pounds*	*Inches*
6	5,200	33
12	10,270	27
15	12,930	24
18	15,660	21
21	18,480	18
24	21,300	15
30	27,430	9
36	33,690	3

The ponton is equipped at each end with a mooring windlass and two rope cleats to provide a suitable means for mooring the ponton in position and for rapid and easy alignment of the ponton when in the bridge. The ponton is rowed when light and under normal conditions by means of six 14-foot oars. The weight of the ponton is approximately 3,100 pounds.

b. Trestles.—The trestle consists of a latticed steel transom vertically adjustable by means of chain hoists which are supported by the upper end of the columns. The transom is supported at any desired position by means of pins that pass through the end plates of the transom and corresponding holes in the columns. Each column has a steel shoe so fastened that it may assume an angle adapted to its footing and still support the column in a vertical position. The trestle comprises seven separable parts: The transom; two columns; two chain hoists and two trestle shoes. The weight of the trestle complete is approximately 1,700 pounds. The transom is of 14-foot span, 19 inches deep, and 10 inches wide. The columns consist of steel tubing.

c. The floor system (see fig. 63).—The floor system per bay consists of 9 balks (roadway bearers), 2 side rails, 16 chess, and a transverse balk. The transverse balk is located at the middle point of the ponton and trestle spans and is rigidly connected to the side rails by means of transverse balk hangers. The purpose of the transverse balk is to equalize the load on the several balks and to transmit to the side rails a portion of the load. The clear width of roadway is 11 feet 3 inches.

d. Hinge (see fig. 62).—The hinge consists of a timber sill 6 by 9 inches cross section suspended by means of hinge sill hangers from each balk of the first ponton span. The shore ends of the hinge balk rest on and are lashed to the transom of the trestle. The river ends of the balk rest free on the top of the hinge sill in a manner which will allow the balks to adjust themselves to changes in gradient of the roadway and to slight changes in the length of the span between the hinge and the trestle.

e. Ponton balks.—The ponton balks are of wood, 5$\frac{3}{16}$ by 7$\frac{3}{4}$ inches in cross section and 23 feet long, giving a span of 16 feet center to center of pontons. The average weight of a balk is 225 pounds. The balks are fastened to the gunwales of the pontons by rigid metal balk fasteners which are tightened by turnbuckles.

f. Trestle balks.—The trestle balks are of wood, 5$\frac{3}{16}$ by 7$\frac{3}{4}$ inches cross section and 16 feet 4$\frac{1}{2}$ inches long. Each end of the balk is equipped with steel fittings which provide means of spacing and fastening the balk to the trestle by rope lashings in a manner to allow for sharp changes in the gradient of the roadway. The average weight of one trestle balk is 160 pounds.

g. Transverse balks.—The transverse balks are 13 feet 6 inches over-all length and weigh approximately 130 pounds. A transverse balk is swung underneath the boat balk of each span at the middle point and is fastened to the side rails over that point by transverse balk hangers (see fig. 63).

h. Transverse balk hangers.—The transverse balk hanger is of steel and consists of two stirrup hooks which engage underneath the bottom surface of the transverse balk and are suspended from a clamping plate which rests on the top of the side rail. The clamps are tightened in place by means of a screw.

i. Chess.—The chess is a wooden plank 13 feet 6 inches long by 11$\frac{3}{4}$ inches wide by 2$\frac{7}{8}$ inches thick. A chess weighs approximately 100 pounds and is a load for two men.

j. Sills.—The sills are of wood 6 by 9 inches by 13 feet 6 inches equipped with metal fittings at each end to facilitate handling and weigh approximately 170 pounds each. The abutment sill and the hinge sill are alike.

k. Hinge sill hangers.—The hinge sill hanger consists of two steel stirrups which fit snugly over the top of the balk and support the hinge sill on a steel plate held to the stirrups by tee-irons fastened by hand nuts.

l. Miscellaneous items.—The *pickets* are of 2-inch extra heavy wrought-iron pipe 42 inches long pointed at the bottom and equipped with a plug at the top. The *anchor* is of the kedge type, 150 pounds in weight and *anchor cables* are of manila rope, 1 inch in diameter. The *oars* are the commercial type 14 feet long. The *pump* is of sheet metal. The *oarlocks* are of a special type. The *boat hooks* are the commercial type 10 feet long, ball pointed. The *rack sticks* are of steel tubing 42 inches long and are used for operating the mooring equipment of the boats, and for constructing and adjusting the trestle. *Manila rope lashings* ½ inch in diameter by 18 feet long are used to lash the trestle balk to the trestle transom and also to lash side rails near their ends to outside roadway bearers. *Manila rope guy lines* 1 inch in diameter are used to guy the trestle columns to near-by trees or deadmen on shore and to anchors cast in the river bottom. A small *motor boat* is provided for towing pontons or rafts from the launching point to their positions in the bridge.

m. Transportation.—The equipage is transported on trailers towed by trucks. There are two types of trailers, one type for ponton loads and one type for trestle loads. The ponton trailer load includes 1 ponton and 11 boat balks. The trestle trailer load includes 1 complete trestle and 18 trestle balks. Accessory items like anchors, buckets, cable, pumps, oars, boat hooks, rack sticks, and axes are carried in the trucks which tow the trailers. The chess are carried in trucks which may also tow the ponton and trestle trailers, but unless trucks of long wheelbase are provided the overhang of the chess may make it impossible to tow trailers behind trucks carrying chess.

117. Canvas-covered ponton equipage.—*a. Ponton.*—The ponton is a collapsible wooden frame, 21 feet by 5 feet 4 inches by 2 feet 4 inches, covered with canvas. When set up for use it weighs about 580 pounds. The maximum safe net buoyancy allowing 4 inches of freeboard is 10,300 pounds. Its displacement is as follows:

Draft	Water displaced	Draft	Water displaced
6	3, 100	22	11, 850
12	6, 300	24	13, 025
18	9, 600	28	15, 350

b. Trestles.—The trestle is of the same type as in the heavy equipage, M1869.

c. Floor systems.—The floor system consists normally of five balks, two side rails, and the necessary chess.

d. Balks.—The ponton balks are 22 feet by 4½ inches by 4½ inches. The trestle balks are 21 feet by 5 inches by 5 inches.

e. Chess.—The chess are 11 feet by 12 inches by 1½ inches.

f. Lashings.—Fastenings are made of rope lashings. (See figs. 64 and 65.)

g. Transportation.—All wagons are of the same type, the heavy ponton chess wagon, and are drawn by 4 mules. The loads are as follows:

(1) *Ponton wagon load:*

7 short balks.
16 short chess.
2 side frames.
1 cable.
1 anchor.
Ponton chess containing 1 ponton cover, 14 transoms, 2 scoops, 20 lashings, 2 boat hooks, 1 pump, 8 rack sticks.
1 axe.
1 bucket.
1 spare singletree.

(2) *Chess wagon load:*

50 short chess.
1 axe.
1 bucket.
Packs containing two spare ponton covers.

(3) *Trestle wagon load:*

7 short balks.
7 trestle balks.
1 trestle complete.
1 sill.
1 half coil of 3-inch circumference rope, 720 feet long.
1 half coil of 1-inch circumference rope, 720 feet long.
1 cap lever.
8 pickets.
1 axe.
1 bucket.

(4) *Ponton tool wagon load:*

Blacksmith's equipment.
Blacksmith's supplies.
Saddler's equipment and supplies.
Spare parts.
Sailmaker's equipment for repairing ponton covers.

118. Location and approaches.—The location of a ponton bridge is usually fixed by tactical requirements, but occasionally the technical advantages of a site may govern. The orders for the construction of a bridge should prescribe only the limits within which the site should be chosen, leaving its exact location to be selected by the engineer officer in charge. The bridge should be located in a straight reach or gentle bend where the bed affords a good anchorage, slopes gradually away from the bank, and is free from snags, boulders, reefs, or other obstructions; where the current is regular, parallel to the banks, and moderate; where the banks are firm, and, if much above the water, have easy slopes and are not rough, broken, or liable to overflow during ordinary rises. A bridge site meeting all these conditions will rarely be found, but as many of them as possible should be secured. A tributary stream may afford concealment for the assembly of materials, in which case a site just below its mount may be better than elsewhere. The width of the stream, velocity of current, depth of stream, rise and fall of tides, variation in width of wetted section, and the frequency and height of ordinary floods should be determined. Except for the measurement of width, only rough data are required.

FORM FOR RECONNAISSANCE OF PONTON BRIDGE CROSSING

Map reference ....

Date .... Party ....

(1) Location of bridge site..

(2) Width of stream..

(3) Maximum depth..

(4) Velocity..

(5) Character of bottom..

(6) Approaches..

(7) Banks..

(8) Number of trestle bays { Right bank.. / Left bank.. }

(9) Number of ponton bays..

(10) Local concealment..

(11) Launching sites..

The width should be determined fairly accurately and, if possible, sufficient data secured as to the depth in order to decide upon the number of trestle spans which should be used. The approach on each side of the bridge should be straightaway whenever it can possibly be secured. The stream should be crossed at right angles if possible. The crossing should be sited so that the pontons, trestles, and abutments will be parallel with the current.

119. Construction.—*a. General principles.*—The principles of constructing ponton bridges described in this paragraph apply to all types of ponton bridges except as noted. The method of construction selected depends upon the character of the stream, the force available, and the tactical situation it may be desired to serve. A tug or power launch is of great assistance in the construction of a floating bridge. Use is also made of outboard motors which are attachable to the pontons or to skiffs.

b. Unloading.—The pontons are unloaded from ponton wagons as near to the river bank as possible, with the rear of the wagons toward the stream. To do this the pontons are unfastened from the wagons and slid from the wagon directly into the water whenever possible. When a ponton can not be unloaded directly into the water, one end is slid from the wagon to the ground and the ponton is then carefully laid down by the unloading detail. The ponton is then dragged or carried to the water and launched. Where the banks are too high to permit of launching the pontons directly into the water, the pontons can be skidded into the water on balks laid from the bank. As soon as the pontons are in the water the anchors are placed aboard. The pontons are then moored at convenient points along the bank. The trestles and other material are unloaded in convenient places near the work, their location depending upon the method of construction to be employed. The canvas type of ponton must be assembled after unloading and carried to the water's edge. One squad makes a suitable detail to unload, assemble, and launch one canvas ponton.

c. Organization.—The personnel required to construct all types of ponton bridges by the method of successive pontons, which is the most usual method, is as follows:

TABLE XXXIX.—*Ponton-bridge construction*

LIGHT EQUIPAGE, M1926

Name of section	NCO's	Pon-toniers	Total
Abutment section	1	8	9
Abutment and trestle spans	1	8	9
Hinge span and balklashers	2	14	16
Balk carriers	1	14	15
Chess carriers	1	18	19
Upstream anchors	2	8	10
Downstream anchors	2	8	10
Trestle guy anchors and ferrying	2	8	10
Side rails	2	6	8
Cables		2	2
Total	14	94	108

TABLE XXXIX.—*Ponton-bridge construction*—Continued

HEAVY EQUIPAGE, M1869, OR LIGHT CANVAS EQUIPAGE

Name of section	NCO's	Pon-toniers	Total
Abutment	1	8	9
Upstream anchor	2	8	10
Downstream anchor	2	8	10
Balk carrier	1	10	11
Balk lasher	2	10	12
Cable	0	2	2
Chess	1	22	23
Side rail	1	8	9
Total	10	76	86

HEAVY EQUIPAGE, M1924

Name of section	NCO's	Pon-toniers	Total
Abutment	1	8	9
Abutment bay	3	12	15
Trestle bay	3	12	15
Hinge span and balk (lashers, boat span)	2	12	14
Balk carriers	2	33	35
Cable		2	2
Upstream anchor	2	12	14
Downstream anchor	2	12	14
Trestle guy anchor and ferrying	2	12	14
Side rails and transverse balk	2	6	8
Chess	1	34	35
Total	20	155	175

A larger number of men than shown in the table may sometimes be used to advantage when great speed is required. One officer is assigned to exercise supervision over the entire operation. One officer is assigned to the construction of the abutment span, trestle span if required, casting of anchors for trestle leg guys, locating deadmen, rigging trestle leg guys and all shore lines both to pontons and trestles. One officer is assigned to supervise the location of the abutment, the location of range poles for aligning the bridge and the casting of downstream anchors and to keep watch over the movements of the details at the piles of materials to see that the material is moved promptly. One officer is assigned to the construction of the hinge span (in those bridges using hinge spans) and, standing on the shore, supervises the casting of anchors and the movements of the upstream anchor detachments.

d. Location of material.—Pontons destined to cast upstream anchors are moored upstream from the bridge site, all others below, except that in streams having rapid currents it may be desirable to float the pontons into place in the bridge from upstream, using a light skiff, if available, to carry and place the downstream anchors. The balks are piled on the left of the entrance to the bridge in the following manner: Two balks are laid on ground parallel to each other and about 18 feet apart. Across these a layer of balks nearly in contact, then two chess directly above the first two balks, then another layer of balks, etc. The chess are piled on the right side of the bridge as follows: Three balks are laid on the ground parallel to each other and about 4 feet apart, on these a course of 10 chess nearly in contact, across these 10 more chess at right angles to the first layer, etc.

e. Preparation of the abutment.—The abutment is prepared by excavating a trench 14 feet long by 1 foot wide by 1 foot deep to receive the abutment sill or sills. These should be horizontal, exactly perpendicular to the axis proposed for the bridge and firmly secured in place by pickets. As soon as the balks of the abutment span are in position a chess is placed against their ends, its upper edge on a level with the chess forming the roadway. It is secured by pickets and by tamping the earth in rear of it. The approach to the bridge is then prepared by cutting down the bank if necessary.

f. Types of abutment spans.—The heavy equipage, M1924, and the light equipage, M1926, are constructed with one or more trestles between the abutment sill and the first ponton span of the bridge. Equipage of the old or improvised types of floating bridges may or may not have a trestle, depending upon whether or not the water at a distance of one span from the abutment sill is of sufficient depth to float a ponton.

g. Construction of abutment span, with light equipage, M1926, or with heavy equipage, M1924.—(1) When the water at a distance of one span from the abutment sill is not deep enough to float a ponton, a cribbage is erected, using 8 trestle balks, in a position approximating the location of the trestle to be erected or approximately 16 feet from the abutment sill. The width of the cribbing should not exceed 10 feet and should be centered with 5 feet on either side of the proposed axis of the bridge. On this cribbing the trestle transom is laid on its side. The trestle columns are then inserted from the river side of the transom and the shoes are affixed to them. A rack stick is placed in the bottom hole of each trestle column resting on the top of the transom to prevent the column from slipping through the transom. Two hand lines 24 feet long are attached to opposite rings on top of each trestle column, and a shore line rope 1 inch in diameter is attached to each trestle shoe. The trestle is raised to a vertical position and steadied by the hand lines. The transom is now shifted on the cribbing to its correct position, the center of the transom on the center line of the bridge and at a distance from the abutment fixed by the length of the trestle balk running from the abutment to the transom. The trestle columns are now lowered until the shoes rest on the bottom by using a rack stick through one of the holes in the column above the top of the transom which permits two men to handle the column. Each trestle shoe is moored to a picket, deadman, or

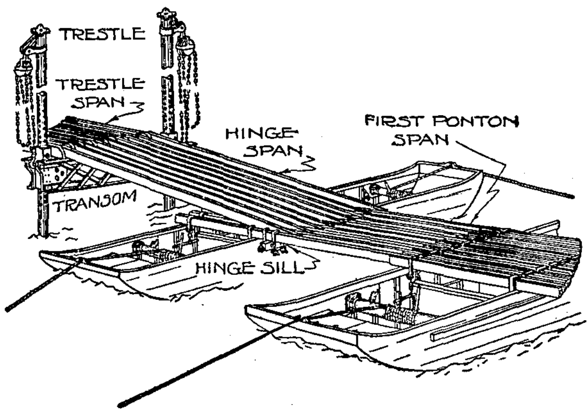


FIGURE 62.—Hinge span, heavy equipage, M1924, or light equipage, M1926

near-by tree on shore. The chain hoists are now placed in the hooks at the top of the trestle columns, and the transom is raised or lowered to a proper position. The trestle pins are now inserted and the chain hoists slackened sufficiently to transfer the load to the trestle pins. The cribbing is now removed.

(2) When the water at a distance of one span from the abutment sill is of such depth that it will float a ponton loaded with a trestle, the use of cribbage to support the transom may be dispensed with. Moor a ponton boat as close to the shore as possible. Lay across the gunwales of the boat 2 chess, one located upstream and the other downstream, approximately 4

feet from the middle bulkhead of the ponton. On the river side of the ponton allow the chess to project beyond the gunwale approximately 18 inches. Lash the chess to the gunwales by means of rope lashings to the rings located along the sides of the ponton. Across the shore ends of these chess lash a third chess parallel to the axis of the boat. Lay the trestle transom on its side across the chess in a position approximately one foot inboard from the gunwale on the river side of the ponton. Assemble the trestle columns so that approximately 12 inches of each leg projects beyond the bottom of the transom. Assemble the trestle shoes. Load the trestle chain hoists, several levers (round sticks 3 inches diameter, 6 feet long), two 1-inch diameter shore mooring lines for trestle shoes, 6 rack sticks, four ½-inch lashings 18 feet long, 7 oars, 2 boat hooks, and 8 oarlocks. Maneuver the ponton over the trestle position with the trestle shoes inshore, and moor the ponton with anchor lines upstream and downstream so that its position may be easily adjusted or aligned. Make fast to a ring on each trestle shoe a 1-inch diameter mooring line for the purpose of mooring the trestle shoe to a deadman or nearby tree on the shore. Carry the free ends of the lines ashore. Slide the trestle columns through the transom until the seventh hole of each trestle column is visible at the bottom of the transom. Place a rack stick through the trestle pin holes on each trestle column immediately above the top of the transom. Slide the trestle along the chess until the bottom of the transom is located approximately one inch outboard of the gunwale of the shore side of the ponton. Center the trestle so that the center of the transom is directly over the middle bulkhead of the ponton. Make fast two hand lines, 24 feet long, to the top of each trestle column, using opposite rings. Raise the trestle to an erect position by the use of the inshore hand lines by lifting the trestle columns, at the same time balancing the ponton on an even keel by loading the chess, laid parallel to the axis of the ponton, with approximately four men. Hold the trestle in an erect position with the four hand lines, two inshore and two held by men on the chess. Space the trestle from the abutment side by means of the two outside trestle balks, with the river ends of the balk *spotted over the* white marks to the extreme right and the extreme left on the river side of the transom of the trestle being erected, and the shore ends of the balk spotted over the white marks to the extreme right and the extreme left on the shore side of the transom of the trestle or abutment sill already in position.

Make fast the two trestle balks to both trestles or trestle and abutment sill, as the case may be, by means of rope lashings. Center the trestle over its position by sighting on range poles located on shore. Lower the trestle columns to position, alternately, in the following manner: Place a rack stick through one of the lower holes of the trestle column; loop around the column and under the rack stick a 1-inch diameter lashing so that the length of the loop is approximately 24 inches. Place a lever in the loop and with the gunwale of the ponton as a fulcrum raise the column slightly. Draw the upper rack stick resting on the transom and lower the column slowly to the full extent of the lever. Replace the upper rack stick and repeat the operation until the trestle shoe rests on the river bottom. Lower the second column in a similar manner. During this operation hand lines should be held and handled by the men in the ponton and ashore in such a manner that the trestle column will be held in an erect position. In the event that the shoe is not lowered to its proper position, raise the column by means of the loop and lever, and repeat the operations of lowering until shoe is properly located. During the lowering of the trestle columns the ponton must be kept on an even keel. Four men on the outboard chess, with two others, one on each of the lateral chess, to shift their weight as required, will accomplish this. Equip the trestle with the chain hoists, and then raise the transom slowly by means of hoists to its position so that the top of the transom sill is 38 inches higher than high-water mark. During the raising operation the transom must be maintained in a horizontal position to prevent canting of columns or shifting of shoes. Make fast the shore end of the trestle shoe mooring lines to a deadman or nearby tree on shore. Bring up and place the trestle balks from abutment sill to trestle transom to act as roadway bearers, lashing them to the trestle transom only. Apply the chess. Apply side rail balks and lash them to the outside trestle balks.

h. Construction of abutment span, heavy equipage, M1869, or light canvas equipage.—The trestle is assembled and placed by bringing a ponton in close to the abutment sill and laying two construction balks from the interior gunwale of the ponton to the shore. The trestle cap may be suspended from these by lashings or it may rest upon them. The claws of two trestle balks are engaged on the cap and the ponton is pushed off until the shore ends of the trestle balk can be engaged on the abutment sill. The legs are inserted in the mortises of the cap, the shoes placed and keyed and the legs driven down into the bed of the river. The pins and wedges are then placed to hold the transom and the ponton and construction balks are removed.

i. Trestle spans.—Trestle spans are used to reach from the shore to a point where the depth of water is sufficient to float the first ponton and to ease the gradient from the abutment to the floating portion of the bridge. Careful use of trestle spans minimizes the work necessary to prepare approaches. The trestles are erected by one of the methods described above, depending on the depth of the water at the trestle site.

j. Hinge spans.—In the heavy equipage, M1869, and in the light canvas equipage, the hinge is usually provided by a saddle placed over the center of the first ponton in the bridge. The heavy equipage, M1924 and light equipage, M1926, are provided with a hinge sill placed between the first and second pontons and suspended by hinge sill hangers from the balks of the first ponton span. (See fig. 62.) This hinge sill is floated under the balk and drawn up into position by means of hand lines. Lash a ½-inch diameter rope loop around the sill and the two balks on both the upstream and the downstream side of the span. Place a rack stick through the loop and twist it until the sill is flush against all balks of the span, then place the two outside hinge hangers and tighten them. Remove the hand lines and lashings and place and fasten the hinge sill hangers connecting the hinge sill with each of the remaining balks of the ponton span. The anchor detachments cast four anchors, two downstream and two upstream at right angles to and approximately 200 feet from the center line of the bridge and on a line with the axes of pontons Nos. 1 and 2 when in their position in the bridge. Moor this first ponton span to its approximate position in the bridge by means of shore lines from ponton No. 1, fastened to stakes or deadmen on shore upstream and downstream. Place the two outside and the center trestle balks in position, shifting the ponton span by means of these balks and the shore lines to its proper position and make fast with the shore and anchor lines. Place the remainder of the trestle balks in position lashing all balks to the trestle transom with rope lashings, and leaving the river ends of the trestle balk resting free upon the hinge sill. The chess are laid in such a manner that the crack between the last chess of the hinge span and the first chess of the ponton span is directly over the hinge in order to provide the desired freedom of action for the hinge. For the same reason the side rails are so laid that the river ends do not project beyond the hinge on the first ponton span.

k. Ponton spans.—There are four methods of constructing the remainder of the bridge: By successive pontons, by parts, by rafts, and by conversion.

(1) By the method of successive pontons the bridge is built out from the shore, ponton spans being added successively

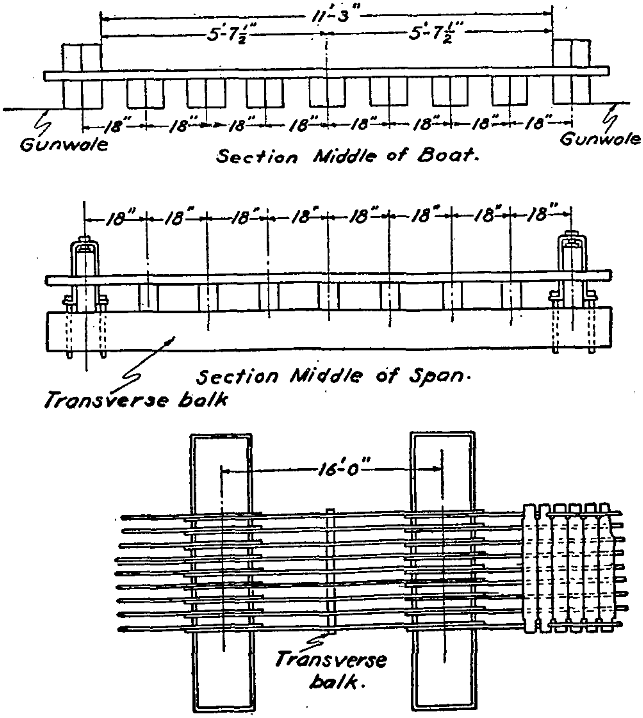


FIGURE 63.—Floor system, heavy bridge equipage, M1924

until the opposite shore is reached. The method of construction by successive pontons possesses the advantage over the others of being applicable to all streams whatever may be their velocity and of requiring the minimum quantity of equipage, the fewest pontoniers and the shortest time for its construction. It is the only method recommended for constructing the bridge with the heavy M1924 equipage. However, the labor of constructing a bridge by this method increases rapidly with the number of bays, on account of the distance that the balk and chess must be carried by hand before being placed in the bridge.

(2) Ordinarily for long bridges (e. g. 40 bays or more in length) the method of construction by parts is used to supplement construction by successive pontons. The bridge is begun at both ends if possible by the method of successive pontons and is pushed out rapidly toward the middle of the stream. The two portions thus formed are connected by parts which have been constructed along the river bank above the bridge.

(3) The method of construction by rafts ordinarily is employed when the passage of a river is to be forced and when the rafts may be constructed unobserved by the enemy, in which case the pontoniers will be exposed to fire but a short time, that is, while the rafts are being floated into position and then connected. In order that this method of construction may be successful, the current must be moderate and there must be a reasonable distance above the bridge positions where the rafts can be constructed unobserved by the enemy. This method is also employed when the bridge is liable to injury from floating bodies as the portion threatened can be readily disconnected, dropped out of the bridge and restored to its place when the danger is passed.

(4) Construction by conversion is the most difficult of the four methods. To insure success, the current must be moderate, the holding ground good and the pontoniers highly trained. The awkwardness of a single man, the dragging of an anchor or the parting of a cable may cause the failure of an entire operation. The opportunity for employing this method successfully will be exceedingly rare.

l. Construction by successive pontons.—The abutment and abutment trestle and hinge span having been constructed, a detail of balk carriers approach the head of the bridge with balk for the next span. As the next ponton arrives, the balk lashers step into it and receiving the end of the balk from the balk carriers fasten them lightly to the river gunwales of the ponton. The balk carriers then push the ponton out by means of the balk and place the balk in position on the shore gunwale of the first ponton. The balk lashers proceed to fasten the balk to the pontons. The chess carrying detail brings up the chess and delivers them to the chess layers who stand on the balk to be covered, facing toward the shore and place the chess shoving each one hard against the preceding one and keeping the score marks in a continuous line on the axis of the bridge. The chess are laid to within 1 foot of the next ponton, leaving room for the balk of the next span to be fastened. As soon as another ponton is brought to the head of the bridge, one of the balk lashing details enters it and prepares to fasten the next set of balks. As soon as a bay has been completely covered with chess, the side rails are laid and fastened by the side rail lashers. If the bridge is to contain transverse balks as in the heavy equipage, M1924, the placing of these balks follows the placing of the side rails. A transverse balk is floated into position under the ends of the balk. The transverse balk is then raised to a position and fastened as follows: Holding the balk in place by means of

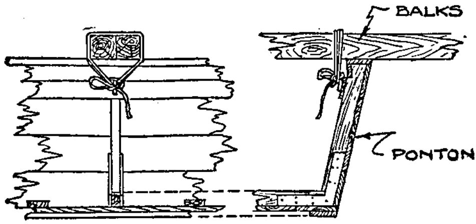


FIGURE 64.—Balk lashing

hand lines, place a loop of 1-inch diameter lashing around each end of the balk and with the rack stick used as a lever through the loop, lever the balk to its position, drop transverse balk hangers over the side rail and between the chess and through the opening in the transverse balk, raise the hooks of the balk hanger until the legs are clear and engage the sticks on the opposite sides of the balk. Remove the lever, loop and lashings, tighten the balk hangers with the rack stick until the transverse balk is used and the side rails are secured with rope lashings and rack sticks.

m. Construction by parts.—Each part may conveniently consist of three bays. To construct the parts, a ponton is moored close to the shore and gangways are temporarily laid to it from the bank. Two other pontons are brought up outside the first and two bays are constructed successively as described in the method by successive pontons, except that the outer bay is constructed first and shoved into the stream by the balk of the inner bay. Enough of the floor is omitted from each end of the part to permit fastenings to be made when the part has been floated into its position in the bridge. Materials for the floor of one bay are laid on the part thus formed which is then pushed off and conducted to the line of upstream anchors where the anchors are cast and the part dropped down into its place in the bridge. The abutment and one or more floating bays are constructed from the shore as described for the method of construction by successive pontons. The parts are then brought into position successively and connected to the bridge. When the opposite shore is reached, the abutment bay is formed as described above.

n. Construction by rafts.—(1) *Heavy equipage, M1869.*—Rafts are assembled in the bridge with the outer pontons of adjacent rafts in contact. The roadway is made continuous by

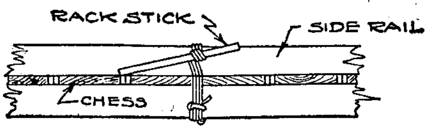


FIGURE 65.—Rail lashing

connecting or false balk laid on top of the floor over the outer balk and connected to form a splice. Devices called rack collars are provided for clamping the false balk.

(2) *Light equipage, M1926, and heavy equipage, M1924.*—Rafts of three or more pontons are constructed as in the bridge by successive pontons except that the chess and side rails are not laid over the end ponton of the rafts. To connect rafts successively to the completed portion of the bridge, float the raft to its approximate position in the line of the bridge. Balk carriers place balks in position on shore portion of the raft and shove the raft out until the balks can be dropped into position on the end ponton of the bridge. The balks are then secured and chess laid in the customary manner. Each raft carries enough additional balks and chess to construct the joint span.

o. Construction by conversion.—The bridge is constructed parallel to the shore and upstream from the bridge site selected. Side rails are lashed on all except the upstream bay. Material is placed on the upstream end of the bridge to make the connection with the far shore when the bridge has reached its final position. The bridge is then allowed to float down until the downstream ponton is within 15 feet of the near abutment.

The material for the near abutment and bay is brought down in a ponton. The upstream end of the bridge is then shoved off and the entire bridge is pivoted on its downstream end, which is not permitted to ground. The movement of the bridge is checked just above the line of abutments and it is slowly shoved into it final position. The far abutment is then constructed and the shore bays are laid.

p. Anchorage of floating bridges.—The anchorage of the pontons of a floating bridge is of the greatest importance. The piers should be so constructed and placed as to present the least obstruction to the current. In nontidal streams, all the bows (if pontons are of a type having bows) are placed upstream; in tidal estuaries, they should alternate up and down stream. The pontons near the shore should be secured by strong cables to rocks, trees, or deadmen on the shore above and below. The anchors provided are sufficient, and in moderate currents it will answer to anchor alternate pontons upstream and every fourth one downstream; the downstream anchors are never attached to pontons which do not have upstream anchors also. In swift currents it may be necessary to anchor every boat upstream. Even in slack water every second or third boat should be anchored both up and down stream to reduce oscillation. The length of cable between anchor and pier should be at least ten times the depth of the stream. Otherwise the anchor is likely to drag and a downward pull is brought on the upstream end of the pier. The anchor must be cast as nearly as possible directly upstream from the position which the pier is to occupy, so that the pier in the bridge will have the same position that it would assume if riding at anchor. Improvised anchors may be made of any heavy materials on hand, as railway iron, pieces of machinery, or large stones. Such anchors must be of considerable weight, as dependence is placed on their mass rather than their attachment to the bottom.

120. Draw spans in floating bridges.—In navigable streams it is frequently necessary to provide a draw span in the bridge to permit the passage of river traffic. This is effected by introducing one or more rafts as described above over the channel of navigation. A swing line is attached to end of the bow of the middle ponton of the draw and the other to the stern of the second ponton from the opening on the side toward which the raft is to be swung. To open the draw, the raft is disconnected from the adjacent pontons and allowed to drop down stream from the bridge by paying out the cable of its upstream anchor. When the swing line becomes taut, the raft will swing into the required place as the anchor cable is further slackened and it is then made fast by the swing line. The raft is replaced in the bridge by casting off the swing line and hauling in the cable of the upstream anchor. The draw may also be formed of two rafts, one dropping to the right and the other to the left of the opening.

121. Trestle bridges.—The trestles of all kinds of ponton equipage may be used in lieu of other bridging materials to form bridges on land or over water courses. The trestles are guyed and in addition the bridge depends for its stability upon the strength of the cleats on the balks and upon the immovability of the abutment sill. The importance of picketing the abutment sill is therefore apparent. To prevent a trestle bridge from collapsing, diagonals are sometimes inserted between the trestles.

122. Maintenance.—*a. Precautions in passing floating bridges.*—Infantry must break step, riders and drivers must dismount and the animals must be led; halting on the bridge should be avoided. If a bridge begins to sway or oscillate considerably the column must be halted and not allowed to resume its march until the swaying has ceased.

b. Protection of floating bridges.—The bridge must be kept clear of drift and other floating objects, especial attention being given to the anchor cables. If the objects are not too large or too numerous they may be passed under the bridge by men working with pike poles from the piers and roadway. Large trees may be disposed of in this way by sawing them up into logs of maneuverable length. Floating objects may be prevented from striking the bridge by a guard upstream or by a draw span in the bridge or by a floating boom crossing the stream obliquely. It is well to station a guard about 1,000 feet above the bridge in boats at different points across the stream and the guard is provided with cables, grapnels, anchors, dogs, hammers, saws, etc. The business of this guard is to anchor or tow ashore dangerous drifting objects. The floating boom is constructed of trees united by chains and forms a continuous barrier to surface drift. Its general direction should form an angle of about 20° with the current giving it a length about 2¾ times the width of the river. A boom is not a very reliable protection. Pontons used in ice should be protected near the water line with chafing pieces. The flooring should be protected from the cutting action of wheels by nailing wheelways of planking longitudinally throughout the bridge.

c. Bridge guards.—A guard should always be posted at a floating bridge. Sentries are posted at each end and if the bridge is long at intermediate points. Sentries turn out the guard whenever the bridge is in danger from any cause. The body of the guard should be stationed near one end of the bridge. The sentries regulate the traffic over the bridge and enforce orders as to right of way of vehicles desiring to cross in opposite directions. A telephone between the ends of the bridge facilitates this operation. The sentry should be provided with a memorandum showing the maximum load permitted on the bridge and the types of vehicles whose characteristics of load and wheel base admit of their passing the bridge. In case of doubt the load should be weighed before being permitted to pass the bridge, and any vehicles exceeding the permissible weight should be partially unloaded or not permitted to enter upon the bridge. The memorandum should also give information as to the location of the bridge, the name of the highway passing over it, and the towns the highway connects. The memorandum should also show the location of alternate crossings of the stream which may be used by vehicles of such great weight that they are not permitted to cross at this point. The officer or noncommissioned officer in charge of a floating bridge must frequently inspect the cables to see that they are not chafing and that the anchors do not drag. He causes lashings and other fastenings to be tightened when they work loose and sees that the pontons are bailed out when they leak or ship water. A suitable depot of spare balks, floor planks, cordage, etc., should be established on shore near one end of the bridge. The guard should be stationed at the same end.

123. Tactics of ponton bridges.—Ponton bridges, by reason of the great rapidity with which they may be constructed and the ease with which preparations for their construction may be concealed from enemy observation and the great mobility of the equipage, have important tactical uses. In the early stages of a forced crossing the pontons are used for the ferrying of infantry to the opposite bank. The same pontons used in the ferriage are later used in the construction of the bridge. The construction operation should be concealed from enemy observation by darkness, fog, or smoke, the latter furnishing the most important means of minimizing casualties during daylight operations by concealing the constructing troops from aimed fire. As the approaches to a ponton bridge are, in general, existing highways, the ponton bridge will usually be erected at the site or near the site of a demolished highway bridge. On account of the necessity for replacing the highway bridge as early as possible, the ponton bridge should be located to one side of the old bridge site. The light ponton equipage is used early in the occupation of the bridge head to pass the combat wagons of the attacking division. Later when it becomes necessary to pass the heavy army loads, a heavy ponton bridge may replace the light bridge. In any event, light ponton bridges should be replaced by fixed

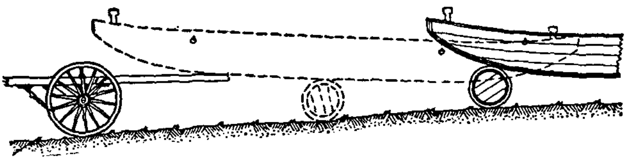


FIGURE 66.—Reloading pontons by casks

or other floating bridges as soon as practicable in order to free the light equipage for tactical uses elsewhere.

124. Reloading pontons on vehicles.—Various methods may be used to reload the pontons on the vehicles as shown in the illustrations in Figures 66 to 69. If available a tractor may be used to pull the pontons up on the vehicles. Another method is to use a portable truck crane to lift the pontons and place them upon the vehicles. Another method is to construct a tripod of

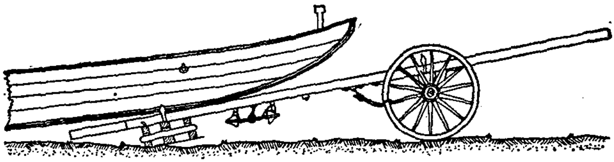


FIGURE 67.—Reloading pontons by unlimbering

balks to the crotch of which is hung a chain hoist. A sling is passed under the ponton which is then raised by means of the chain hoist until there is sufficient clearance to pass the ponton wagon under the ponton. The ponton is then lowered to the wagon.

125. Transporting ponton equipage by rail.—*a. Entraining.*—The necessary railroad flat cars or gondolas are run on a siding with one end at a crossing if possible. All brake handles are then removed, and in the case of end-opening gondolas the end doors are let down to give a crossing between the cars and a clear passage for the wagons. Loading should take place from one end. Wooden crossings are placed between flat cars two to each gap to permit the vehicles to be rolled steadily forward. A ramp composed of a loading trestle, a horse, and material of the equipage is built at the end of the train at which loading takes place. A snatch block is rigged at the far end of the car to

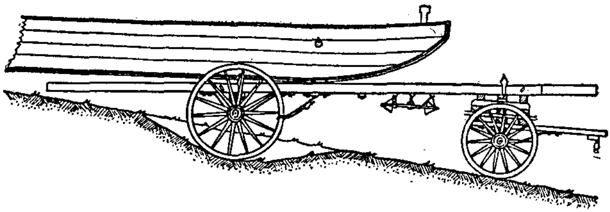


FIGURE 68.—Reloading pontons by lowering rear wheels

which the ramp leads, and a rope is run through the block. A loading hook is fastened to the end leading directly down the ramp. A pair of mules in lead harness is hitched to the rope. As each vehicle is brought to the end of the ramp, its team is taken out and the loading hook on the rope is placed in the ring at the end of the tongue. Two men take hold of the tongue and guide the vehicle while it is pulled aboard by the mules attached to the end of the rope. As soon as the vehicle is aboard, the loading hook is released and a suitable detail runs the vehicle by

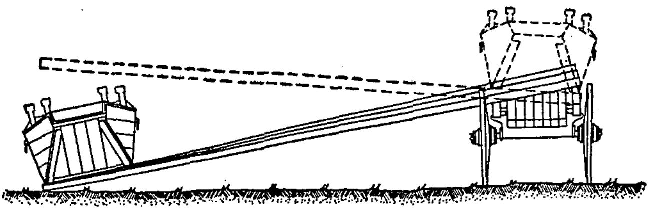


FIGURE 69.—Reloading pontons by the side

hand to its place on the train. The other wagons are brought up in turn and loaded in the same manner. An officer or noncommissioned officer sees that each wagon is properly placed on its car, tongue removed, front truck reversed when necessary, and brake set, and then sends the detail to bring up another wagon.

b. Blocking.—Each vehicle is secured to the car by spiking a 3 by 4 inch scantling on the inside and outside of each wheel, and to these scantlings are spiked three cross scantlings, one in front, one in rear, and one through the wheel between the spokes. Each vehicle to be loaded requires 48 linear feet of 3 by 4 inch scantling. As soon as a vehicle is blocked it is lashed on with an anchor cable. All vehicle brakes are set and tied fast with a lashing. Wagon tongues may be lashed to the vehicles or placed in the boats. Car brakes are then replaced and, if gondolas are used, the end gates are raised.

c. *Care of equipage en route.*—An officer with a detail of troops and the necessary animals to move the vehicles should accompany each section or train carrying ponton equipage. Two men ride with the vehicles, moving from car to car from time to time to see that the material rides well. When any of the material is seen to be in danger, the conductor is notified. At stops all blocking and lashings are examined, and, if necessary, are put in order.

d. *Detraining.*—Detraining takes place from one end of the train, preferably that opposite from the one at which entraining took place. The blocks and lashing are removed and a ramp is constructed if necessary. The brake handles are removed and crossings put in place between cars. The front truck of the first vehicle is turned around and the tongue inserted. A block is rigged as for entraining. The loading hook is secured to the rear of the vehicle, while a turn around a convenient object is taken with the other end of the rope, which is held by two men. Two men guide the vehicle, which is then let down the ramp, the men on the rope slacking off slowly and steadily. As soon as the vehicle is off the ramp its team should be attached and the vehicle removed without delay. Other vehicles are moved by hand to the ramp and unloaded in the same manner.

126. Transporting ponton equipage by water.—a. *Shipments by water.*—It is sometimes desirable to move ponton equipage by water. In such cases it may be rafted. The number of rafts in a tow and the distance between them are governed by the anticipated roughness of the water. Each raft should always have a crew of four men provided with oars for steering and with spare lashings for repairing damages. When it is required to transport carriages, they may be taken apart and packed into the pontons; but if the water is comparatively smooth, rafts are formed of two pontons covered with a platform, thus presenting the appearance of one bay of a bridge. This platform will carry a number of the vehicles.

b. Oversea transportation.—When equipage is to be moved overseas the loads are removed form the carriages and the latter are taken apart for shipment. In loading the following general rules should be observed: Each vehicle, its load, animals, harness, and driver should all be on the same vessel. When practicable, pontons are stored where they can be readily gotten at for calking en route and for use in landing. Harness for each team is packed in sacks and plainly marked for identification. If the landing takes place at a wharf each vehicle is set up, loaded, and driven off as soon as possible to clear the wharf. If the landing be by lighters rafts may be made of the boats and used as lighters. Animals may be swum ashore, or, if the water be calm, may be taken aboard the rafts.

127. The Lampert footbridge.—*a. Description.*—The Lampert footbridge is a floating footbridge, the buoyant supports of which are small boats consisting of collapsible wooden frames over which canvas paulins are stretched. The walkway is formed of floor sections which span the intervals between boats, their ends resting upon the intermediate frames of the boats. On one end of each floor section is a saddle piece which fits in the notches of the intermediate frames of the boat. The other end of the floor section is fitted with hooks which engage upon the saddle piece of the section ahead. The dimensions of the parts are shown in Figure 70. To construct a unit of the bridge 285 feet in length requires the following parts:

- 24 collapsible boat frames.
- 24 canvas boat covers, rectangular, 10 feet 5 inches by 6 feet 10 inches, with 3 lashing hooks per side, 2 lashing hooks per end.
- 24 lashings for canvas boat covers, ⅜ inch diameter, manila rope, 22 feet long.
- 1 special saddle piece for launching first boat. This is of wood, 3 inches by 1½ inches by 2 feet 1¾ inches, with cleats.
- 25 floor sections.
- 26 handrail posts.
- 1 handrail rope, ⅜ inch diameter, manila.
- 1 anchorage cable, ¼ inch diameter, wire rope.
- 24 anchor lashings, 25 feet long, each equipped with a harness snap at one end.
- 4 guy lines, ½ inch diameter, manila rope.
- 12 mooring stakes, 20-inches.

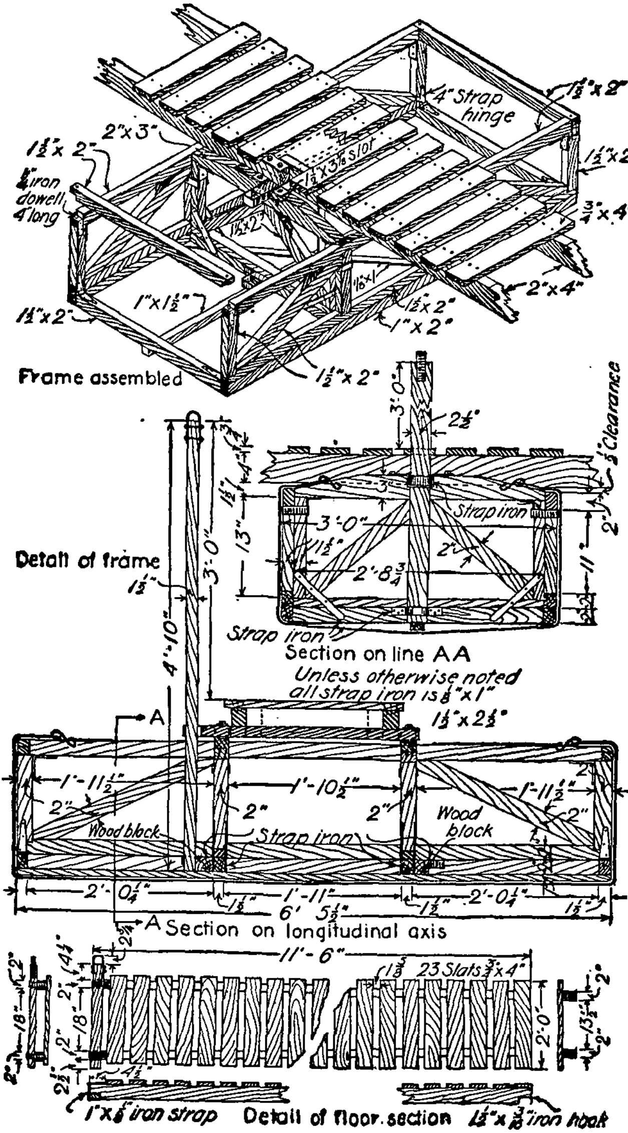


FIGURE 70.—Lampert footbridge

In addition to the above items, a unit of bridge equipage includes mauls, paddles, boat hooks, extra ropes, extra lashings, spare parts, repair materials, and tools. The complete unit weighs approximately 4,500 pounds and when dismantled can be transported in one 3-ton truck or two 1½-ton trucks.

b. Construction.—The boats are assembled on the shore and piled on the upstream side of the bridge site. Two men swimming, wading, or paddling in one of the boats, cross the stream carrying one end of a handrail rope, to the other end of which is made fast the anchorage cable. Upon reaching the far shore they pull the cable into position and make it fast to trees, posts, or holdfasts located about 30 feet upstream from the bridge and as near the water level as possible. If necessary the placing of the cable may be postponed until after the bridge has been completed, the alignment during construction being maintained by guy lines. The first boat is launched and the special saddle piece is engaged in the notches of the intermediate frames. The hooks on one end of the first floor section are engaged on the special saddle piece and the boat is shoved out. The saddle piece on the other end of the first floor section is then dropped into place on the intermediate frames of the second boat. The floor section which is to be used to connect the first boat with the opposite shore is now laid on top of the first bay. Another floor section is brought up, its hooks engaged over the saddle piece of the first, and the entire bridge is again shoved out. The construction is continued in this manner until completed. The floor sections are pinned together and the anchor lashings put into position as the bridge is constructed. The normal method of anchorage is by means of the anchorage cable and lashings. On spans under 100 feet in length, where the current does not exceed 2 miles an hour, anchorage is not essential. The entire unit can be erected in about 35 minutes by a crew of 12 men. The 12-man crew will be divided as follows:

Noncommissioned officer	1
Carrying boats and floor sections	4
Fitting floor sections to boats	2
Maneuvering boats	1
Pinning floor sections together	1
Adjusting anchorage ropes	1
Taking cable across stream	2
Total	12

The time of construction may be materially reduced by increasing the number of men engaged in assembling the boats and carrying them to the site.

128. Kapok footbridge.—*a. Description of unit.*—The kapok footbridge is a floating footbridge, the buoyant supports of which are wooden crates containing kapok pillows. A unit of this bridge consists of twenty-two 12-foot sections fastened together at the ends, making a total length of bridge of 264 feet. Each section is a complete raft, 11 feet 11⅝ inches long, 3 feet 1⅜

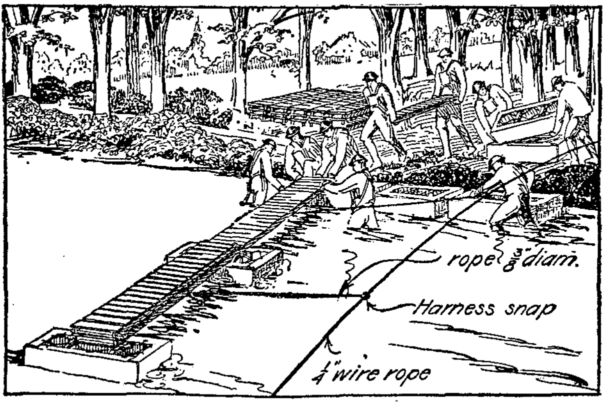


FIGURE 71.—Launching Lampert footbridge

inches wide, by 6⅞ inches deep. It is provided with 6 handles of rope, 3 on each side, for carrying purposes; 2 handrail post sockets located amidships on the outer edge of the section and 4 end-fastening devices. The walkway consists of the tops of the rafts when in place in the bridge and no additional flooring is necessary. Raft clips are provided to prevent vertical end displacement between successive sections. Each section has approximately 180 pounds displacement for each inch of draft. A section used as a raft can transport three men safely. The assembled bridge is capable of passing a column of infantry soldiers in single file with full field equipment. One complete unit of bridge (264 feet) can be transported in two 1½ ton trucks.

b. Component parts.—A unit of kapok bridge consists of the following components (including accessories):

22 kapok rafts.

44 handrail posts.

8 wooden stakes 2 by 30 inches.

600 feet manila handrail rope ½ inch diameter.

56 manila rope lashings ⅜ inch diameter, 7 feet long, with a 3-inch eyelet spliced into one end.

2 manila rope snubbing lines ½ inch diameter, 720 feet long.

2 boat hooks.

2 paddles.

50 raft clips, with attached lashings.

c. Construction.—The entire bridge, consisting of the required number of rafts, with accessories, is assembled on shore in the vicinity of the bridge site, the end of each successive raft being butted against the end of the preceding raft, two raft clips passed over the joint and the rafts fastened with lashings passing over the end-fastening devices and outside of the raft clips. As the clips restrict the flexibility of the bridge they may be omitted if very uneven terrain is to be passed over in carrying the assembled bridge to the launching point. The lashings without attached clips are provided for this purpose. The handrail posts and handrail ropes are affixed.. Snubbing lines are fastened to the first raft. When the bridge has been completely assembled all men except those manning the snubbing lines take hold of the rope carriers on command, raise the entire unit of the bridge, carry it to the bridge site and launch it into the water. In order to prevent congestion it is very important that each carrier run clear of the launching point as soon as his section of the bridge has been launched. The snubbing lines are manipulated to hold the alignment true. The pickets are driven into the ground on each bank as holdfasts and the ends of the bridge are made fast to them. Six men per raft are needed to carry the bridge to the site, but reliefs should be provided if the bridge site is at a considerable distance and the bridge must be carried rapidly. The entire unit can be assembled in about 15 minutes and after arrival at the bridge site can be launched and put to use in about 1 minute.

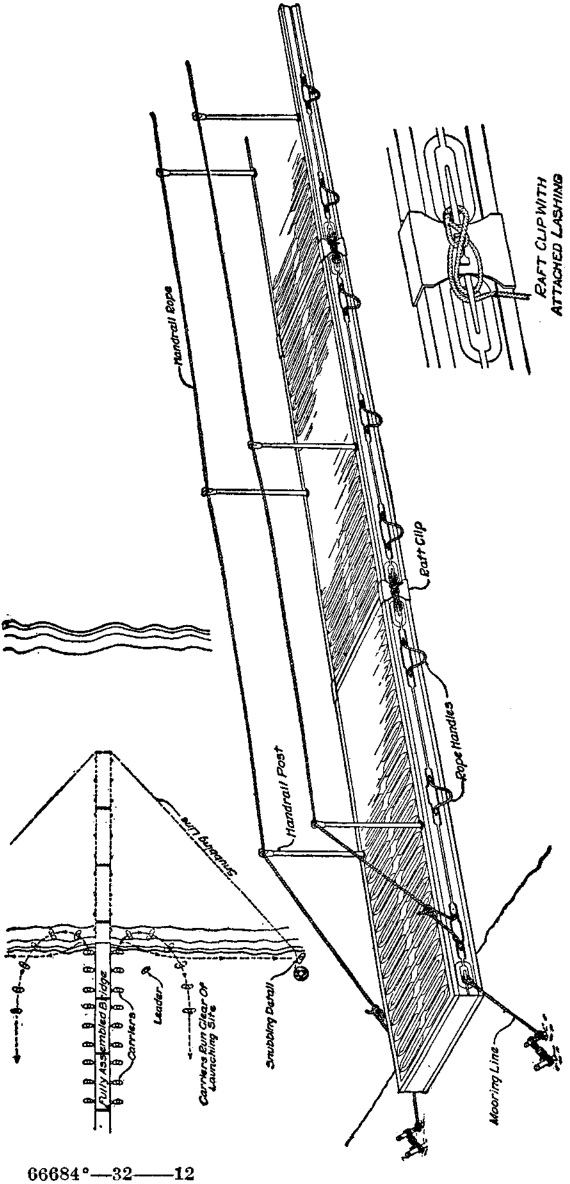


FIGURE 72.—Kapok footbridge

CHAPTER 3

MILITARY RAILWAYS

SECTION I

GENERAL PRINCIPLES, CLASSES AND TYPES

129. Definition of a railway.—A railway consists of a roadway including track, bridges, tunnels, and culverts, over which trains move between terminals; a signal communication system for the transmission of information for the operation of trains; terminals, including yards for receiving, classifying, and forwarding trains; engine terminals for the servicing of locomotives and the making of light or running repairs to locomotives and cars; repair shops for major repairs to locomotives and other rolling stock, provided usually in the proportion of about one set of these facilities for each two or more railway grand divisions; loading and unloading facilities for handling the freight and passengers which the railroad transports; and fuel and water stations for the supply of the locomotives en route between terminals. At various points between the terminals are way stations consisting of buildings, grounds, tracks and appurtenances for receiving and discharging freight and passengers. When the main line consists of a single track, passing tracks are provided at intervals of about 10 miles to permit trains to pass one another.

130. General method of operation.—*a. Operating divisions.*—In general, a railway system is made up of several coherent and self-contained units called divisions of from 50 to 100 or more miles in length. Trains are operated over the division by crews and locomotives assigned to the division.

(1) Freight originates on a division in one of two ways; it may be received from connecting divisions of the same or another railway at division or junction points or it may be loaded on cars on loading tracks within the division itself.

(2) All lading is moved on waybills issued by the agent of the railway, showing the names of shipper and consignee, point of loading and destination, route, and authority for movement. These waybills accompany the train in which the car is moved.

(3) When an incoming train from another railway division or connecting line arrives at a terminal it is pulled into a receiving yard where the road engine is detached and sent to the engine terminal. The train is then inspected. The waybills are delivered to the yardmaster's office, where they are assorted into groups according to the destination of the cars they represent, and a switching list is prepared from which the yard crew breaks up the train and classifies the cars according to their several destinations.

(4) When enough cars have been switched into one of the tracks in the classification yard to make up a train for a certain destination or a group of destinations that may be handled conveniently in the same train, the cars are pulled into another yard called the forwarding yard, where they are inspected to see that the air connections are operating properly and to discover any defects in the equipment. A road engine is coupled to the train, the train crew takes charge, the waybills are given to the conductor, and the train proceeds on order of the train dispatcher out of the forwarding yard to its destination.

(5) Upon arrival at the next classification yard the train is reclassified by a yard-switching crew for either local delivery or for transshipment to another destination. Upon arrival at its final destination the train is broken up for consignees and the cars are delivered to the proper sidings.

b. *Train movements.*—Movement of trains is made upon schedule or by train orders. In either case a train has certain definite rights which are fixed by its class, its direction, or its train order. Trains are operated in general by a fixed time-table. The time-tables are so planned that the trains are kept a certain distance apart for safety. This distance is measured either by the time interval or the space interval. When operating on the time-interval method, trains are dispatched in accordance with train orders which govern movement from one terminal to another where orders for further movement are received. When operating under the space-interval method, the interval between trains is measured by distance instead of time. The road is divided into sections or blocks, in each of which only one train is allowed full rights at a time.

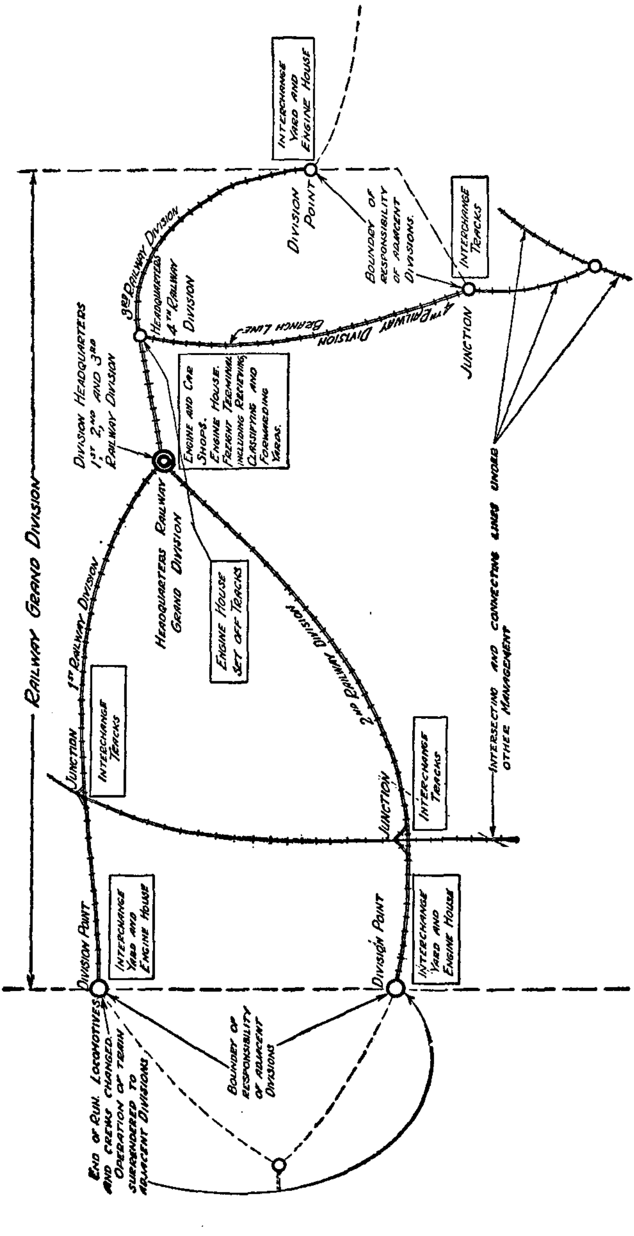


FIGURE 73.—Typical railway grand division

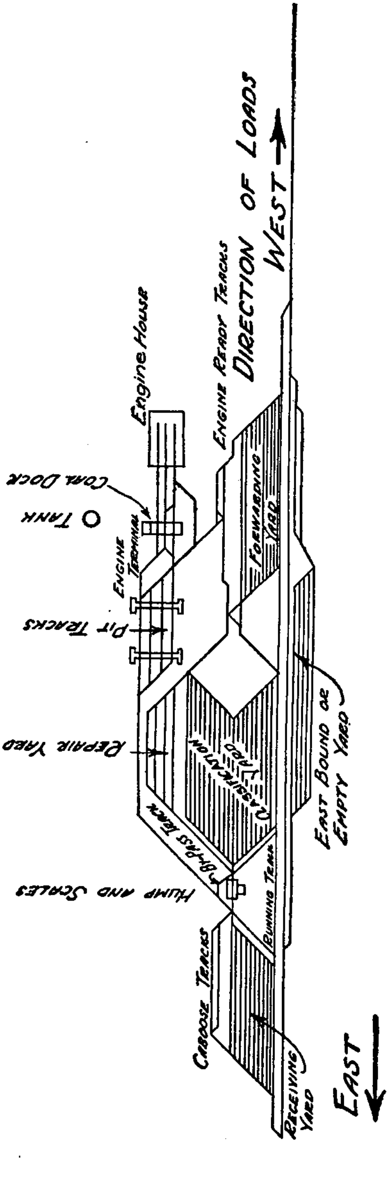


FIGURE 74.—Conventionalized terminal yard layout

131. Comparison of military and civil railways.—The foregoing outline of the functions of a railway will serve to describe the operation of both military and civil railways whether standard or narrow gauge. However, the difference between war and peace conditions will cause a wide departure of military from civil railroad practice. Some of the conditions of military railroad service are as follows:

a. Quick results for a short period of time are the first consideration.

b. Speed requirements are moderate and practically uniform for all traffic.

c. The roadbed, track, and equipment are subject to damage beyond that resulting from the operation of the road or from the elements. A civil road is operated on the presumption that the track is safe; a military road must be operated on presumption that the track is unsafe.

d. The railway will usually be in a fair but unequal condition, often hastily restored after partial demolition. The operation of the whole will depend on the condition of the worst parts.

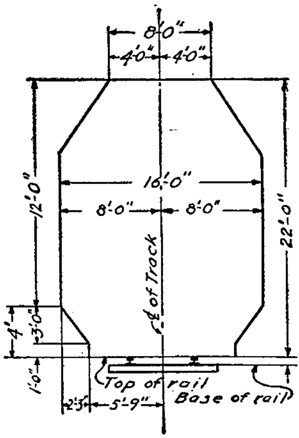
e. A military road is best operated with an ample supply of motive power and rolling stock, and at moderate speed. On a civil road the tendency is to increase speed and loads to economize motive power. The known relations of equipment and mileage on civil railways may not be applicable to military railways.

f. In the construction of military railways rapidity of construction takes precedence over other considerations, and the proportion of temporary work is usually high, owing to the necessity for getting traffic over the line as early as possible.

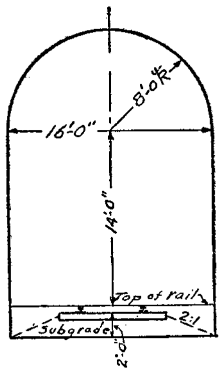
132. Length of military railway division.—There is no material difference between the length of a civil and a military railway operating division. The limiting feature is the capacity of the locomotive. Generally speaking, a fair average locomotive run is about 100 miles. If possible, this should be increased rather than decreased. It should be noted that it is just as important to run maximum tonnage trains on military railways as it is on civil railways. The availability of locomotive terminal sites is what fixes the actual engine run and hence fixes the length of the operating division.

133. Gauge.—The word "gauge" indicates the width of the track between the inner edges of the heads of the rails when newly laid. Standard gauge is 4 feet 8½ inches. Narrow gauge varies from 24 to 44 inches. Broad gauge is wider than standard gauge. The gauge of railways is different in various countries but most of the railways are standard gauge.

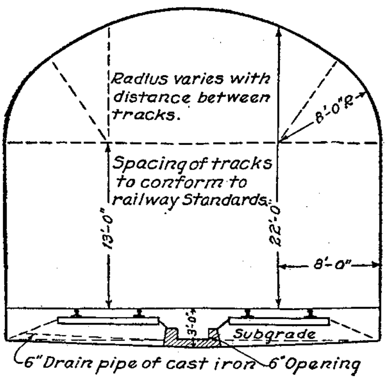
134. Roadbed.—*a. Subgrade and ballast.*—The roadbed is the support prepared for the track. It generally consists of the sub-



① For bridges



② For tunnel, single track



③ For tunnel, double track

FIGURE 75.—Standard clearance diagrams for bridges and tunnels

grade and the ballast. The subgrade is the surface of the cut or fill prepared to receive the ballast. The ballast affords drainage and distributes the load over the subgrade. The following materials will serve as ballast: Gravel, crushed rock, slag, shells, cinders, and even sand if nothing better is obtainable. On account of the great quantity of materials required to ballast track, consideration should be given on military railway construction to the feasibility of dispensing with ballast and laying the ties directly upon the subgrade in dry country or where the native earth is stable and drains readily. In this case the roadbed should be shaped and dressed as shown in Figure 76 ②.

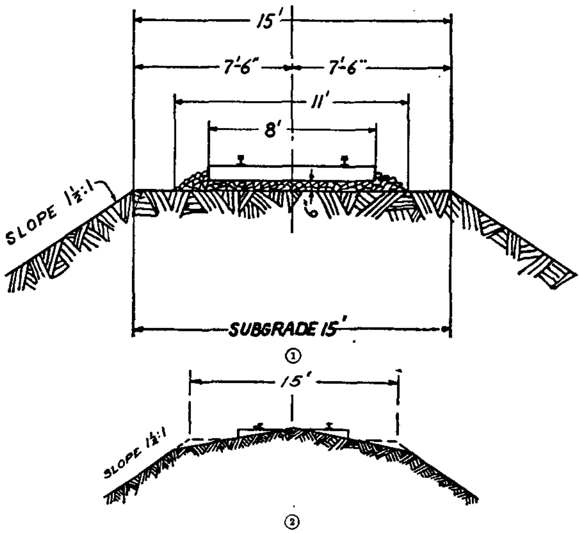


FIGURE 76.—Standard gauge roadbed section on embankment

b. Dimensions.—For standard gauge single track the roadbed should be 15 feet wide on embankments or 14 feet wide in cuts; for double track not less than 27 feet wide on embankments and 26 feet wide in cuts. Parallel tracks are spaced not less than 13 feet center to center.

c. Clearance.—Figure 75 shows the American Railway Engineering Association standard clearance diagrams for bridges and tunnels.

135. Ties.—Ties for military railroads are made of the most available wood, and should be 8½ feet long, 6 to 7 inches thick, and 8 to 9 inches face, top, and bottom. They should be spaced 20 inches center to center, as a rule, but if the ties are broad, it may be necessary to increase this distance to allow 12 inches of clear space between them for tamping.

136. Rails and connections.—*a. Rails.*—The size of rails is designated by the weight per yard in pounds. The name of the manufacturer and the weight per yard are rolled in raised letters on the web of each rail. The tracks of the main line on most civil railways in the United States are now laid with rails weighing from 85 to 100 pounds per yard, and several roads with heavy tonnage have adopted as standard sections weighing up to 136 pounds per yard. For most military purposes a light rail 60 to 85 pounds will suffice. The length of rails varies from 30 to 39 feet, the majority of rails in present use being 33 feet long.

b. Connections.—The connections used for the ends of rails are either splice plates or angle bars and consist of two specially formed bars which fit the rail on each side and are drawn tight by bolting through holes in the ends of the rail. They are desig-

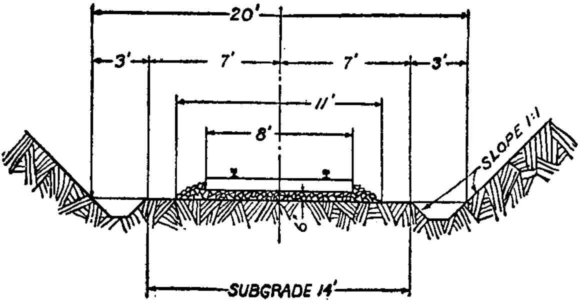


FIGURE 77.—Standard gauge roadbed section in excavation

nated by the weight and section of the rail which they are designed to fit and are further designated by the spacing on the bolt holes measured center to center. For example, an angle bar designated as "100-pound ARA–B, 7–4–7" indicates an angle bar to fit a hundred-pound American Railway Association, Type B, section rail drilled in such a manner that the four bolts will be spaced 7 inches, 4 inches, and 7 inches center to center, when the joint is connected. (See fig. 78.) The standard joint has four bolts. Joints are classed as suspended or supported. The suspended joint has a tie under each end of the angle bar, the actual junction of the rails being unsupported. The supported joint has a tie directly under the junction of the rails. When two rails of different weights are joined a compromise joint is used. When no compromise bars are available, a joint, safe for slow movement, may be improvised by supporting the joint on a large tie and shimming the end of the smaller rail with a tie-plate, angle bar, or other solid materials.

137. Auxiliary tracks.—*a. Sidings.*—A siding or passing track is a track parallel to the main track and connected with the main track at each end.

b. Spur.—A spur track is a track turning out of the main track with a stub end.

c. Crossover.—A crossover is a track forming a connection between two parallel tracks at a point other than the ends of the tracks, enabling cars or trains to pass from one track to the other.

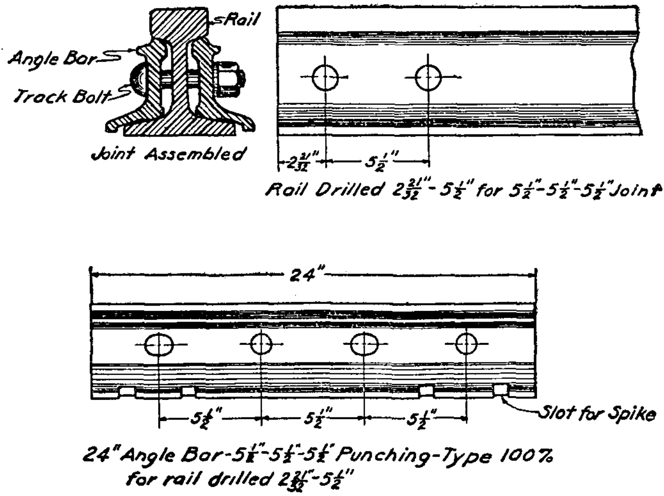


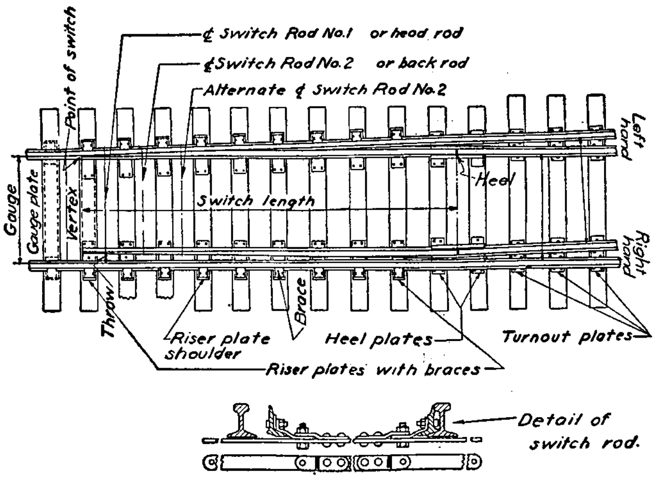
FIGURE 78.—Rail joint

d. Ladder track.—A ladder track (fig. 94) is an arrangement for connecting successively the trackage of a yard for greatest convenience and compactness.

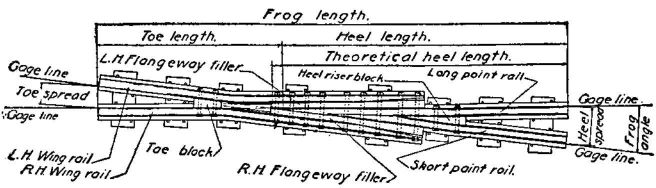
e. Y tracks.—A Y track, or wye, consists of a principal track and two connecting tracks arranged like the letter "Y" with the top closed, by means of which engines and trains may be turned around. A loop may serve the same purpose.

138. Switches.—A switch is a device for connecting auxiliary tracks to main tracks or to each other. It consists of several parts which are shown and named in Figures 79 and 93. The layout plan (fig. 93) and Table LIII furnish the necessary measurements and dimensions of timber for the installation of the most commonly used switch.

139. Switch stands.—A switch stand is a mechanism by which a switch is thrown, locked in position, and indicated for the information of those in charge of train movements. It is usually furnished with a lamp and banner signal.



① Split switch



② Frog

FIGURE 79.—Nomenclature of split switch and frog

140. Guard rails.—Guard rails may be divided into three classes, determined by the functions they perform.

a. The *turnout guard rail*, which is designed to prevent the wheel flanges from striking the points of frogs in turnouts and crossings.

b. The *curve guard rail* for guiding the flanges of wheels of locomotives and cars, while movement is being made over the sharper curves.

c. The *bridge guard rail* to prevent derailed wheels from running off the ties on a viaduct, bridge, or trestle. Guard rails in the first and second classes are placed the standard flangeway distance (1¾ inches) from the main rail, while those in the third class should be placed so as to be struck by a derailed wheel before the opposite wheel strikes the guard timber.

141. Rolling stock.—*a*. The rolling stock consists of the locomotives and cars.

b. Locomotives are classed by the number and disposition of their wheels in the three following groups in the order named:

Forward truck wheels.
Drivers.
Rear truck wheels.

Thus an engine with 2 forward truck wheels, 4 drivers, and 2 rear truck wheels in indicated by 2–4–2, etc.

c. The cars include coaches, sleepers, box cars, stock cars, flat cars, gondolas, cabooses, and special cars such as refrigerators, wrecking cars, hospital cars, and kitchen cars. For data as to dimensions and capacities see Tables XL and XLI.

TABLE XL.—*Dimensions and capacities, typical standard gauge rolling stock*

Class	Dimensions				Capacity				
	Length inside measurement (feet)	Width (feet)	Height (feet)	Approximate weight (empty in tons)	Tons	Cubic feet, approximate	Floor space, square feet	Animals	Men (allowing about 8 square feet per man and equipment)
Box	34	8	7	15	30	1,900	272	13	34
	36	8	8	20	40	2,300	288	14	36
	40.5	8.5	8	23	50	2,750	344	17	43
Flat	38	9	------	17	40	------	342	------	------
	40	9.2	------	20	50	------	370	------	------
	42	9.5	------	25	70	------	399	------	------
Stock	36	8.5	7.6	14	30	2,300	306	15	------
	36	8.5	8	18	40	2,450	306	15	------
Gondola	34	8.5	2.6	20	40	720	289	------	------
	40.5	8.8	2.6	25	50	890	354	------	------
	46	9.5	3	30	70	1,310	437	------	------
Automobile	36	8.5	8	20	40	2,450	306	15	38
	40.5	8.8	9	24	50	3,250	364	18	45
Tank	35	6.5	------	20	40	8,000 gals.	------	------	------
	33.5	7.2	------	25	50	10,000 gals.	------	------	------
Refrigerator	30	8	7	16	30	1,680	240	(1)	(1)
	33	8.3	7.6	21	40	2,060	275	(2)	(2)
Baggage	60	9	------	50	------	------	540	------	------
Caboose	31.5	8.5	6.8	20	------	------	------	------	------
Diner	80.5	------	------	80	------	------	------	------	------
					Passenger capacity				
					2 per double seat	3 per 2 double seats	3 per section		
Coach	63	------	------	60	70	52	------	------	------
Sleeper, 12 sections and drawing room	74	------	------	70	------	------	40	------	------
Sleeper, 16 sections	74	------	------	70	------	------	48	------	------

[1] Ice capacity, 4 tons.

[2] Ice capacity, 5 tons.

TABLE XLI.—*Standard gauge railway—Maximum bulk loadings for freight cars*

Rated capacity of cars in tons	30	40	50
Items	Actual capacity of cars in tons		
Ammunition	30	40	50
Barbed wire	30	40	50
Blankets, baled	27	32	40
Bread	19	24	30
Brick	30	40	50
Burlap, rolls	22	28	35
Cable, steel	30	40	50
Canned goods, boxes	30	36	45
Cement	30	40	50
Chicken wire	18	20	25
Clothing, baled	27	32	40
Coal	30	40	50
Coke	18	24	30
Flour	30	40	50
Frogs and switches	30	40	50
Gravel	30	40	50
Harness and saddling	18	20	30
Hay, baled	15	14	20
Iron, corrugated	30	40	50
Meat	15	24	35
Motor-vehicle parts	24	28	40
Nails	30	40	50
Oats	18	24	30
Pipe, iron	30	40	50
Rail	30	40	50
Rifles, in chests	30	40	50
Rope, manila	18	24	30
Sand	30	40	50
Sandbags	21	24	30
Stone, any form	30	40	50
Sugar	30	40	50
Tar paper	15	20	30
Telephone wire	30	40	50
Tentage	15	20	30
Ties, track	19	26	32
Timber, logs	18	24	30
Timber, sawed	21	28	35
Tires, pneumatic	18	24	40
Tools, engineer	30	40	50
Tools, shop	30	40	50
Tools, truck	30	40	50
Track, fastenings	30	40	50

NOTE.—A rated capacity in tons of a car does not mean that this rated tonnage of all articles can be carried. This table shows the tonnage of military freight which can be carried in freight cars of common rated capacities.

142. Trains.—*a. Types.*— (1) In the United States the composition of a standard train, if used, is based on the use of box cars for men, supplies and equipment; box cars or stock cars for animals; flat cars for vehicles; a box car for use as a kitchen car; a coach or box car for officers and a caboose for railway personnel.

(2) In considering the composition of different standard trains it must be borne in mind that box cars will have to be specially prepared in order to use them for troops or for animals. For troops, the problem of ventilation is simple; openings of sufficient size can be made near the roofs of the cars without damaging them or interfering with their use for all purposes. Doors can usually be kept partly opened.

(3) For animals, the use of box cars in place of stock cars is feasible. The capacity is taken as the same as stock cars. To use them to full capacity it will be necessary to provide lattice doors or other means of giving good ventilation that will at the same time keep the heads of the animals inside of the cars. Large openings in doors covered with heavy wire could accomplish this.

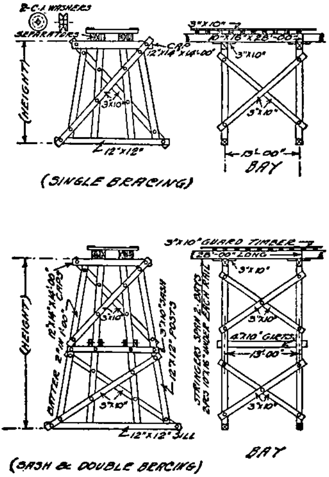
b. Limitations.—In order to be available for moving troops quickly, which is the only real reason for the existence of standard trains, they must be able to reach the point where the troops are to entrain within a few hours at most. To enable them to do this they must be held near the theater of operations where they probably will be needed, and must be used for no purpose that will interfere materially with the use for which they are intended. This means that their use will be limited generally to the movement of troops within or between theaters of operations.

143. Bridges.—*a. General.*—A discussion of the design and construction of bridges is given in chapter 2. Figures 80 and 81 and Tables XLII and XLIII show the form of construction and bill of materials for pile and trestle bridges. Figure 81 shows the floor system for these bridges. A railroad bridge should not be built on an incline if it can be avoided. The approaches at each end should be straight and nearly level for a distance of at least twice the maximum train length. Foundations must be especially unyielding as settlement is more troublesome than in other bridges. In double-track bridges the distance from center to center of tracks must not be less than 13 feet.

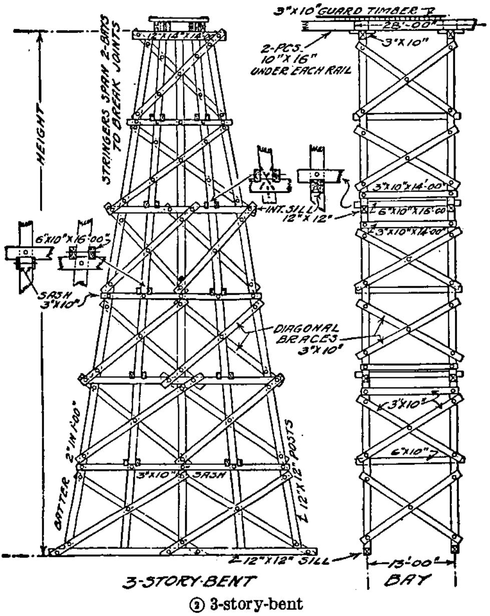
b. Creeping and slewing.—The ties of a railway bridge should be spaced from 4 to 6 inches apart, and about every sixth tie should be fastended to the stringers by nailing a block to the stringer that completely fills the space between that tie and the next. This prevents creeping of the track on the bridge. The track is prevented from slewing sideways by turning every fifth tie on edge and dapping it to fit the stringers.

c. Guard rails and guard timbers.—Guard rails are rails laid inside the track rails to keep derailed cars in line, and are desirable but not essential. They may be of lighter rail than the track rails, and may be laid as near to the track rails as the rail flanges will permit, and should be bent and brought together on the approaches. Guard timbers are longitudinal timbers placed outside of the track rails to maintain the spacing of the ties. They may be dapped to fit between the ties or bolted to them. They are not used on ballast deck bridges.

d. Up to a height of 10 feet, crib piers can be built more rapidly than trestles if the material is at hand. Above this height the trestle has the advantage.



① 1-story-bent



② 3-story-bent

FIGURE 80.—Timber trestle bridges for standard gauge railways

TABLE XLII.—*Standard gauge railway—Bill of materials for timber trestle bridges*

TIMBER
(See fig. 85)

Bent, 12 feet high	Bay, 13-foot centers	Bent, 18 feet high	Bay, 13-foot centers
1 cap 12″ x 14″ x 14′ 00″. 1 sill 12″ x 12″ x 18′ 00″. 4 posts 12″ x 12″ x 12′ 00″. 2 braces 3″ x 10″ x 20′ 00″.	2 stringers 10″ x 16″ x 28′ 00″. 2 guard pcs. 3″ x 10″ x 16′ 00″. 4 braces 3″ x 10″ x 18′ 00″.	1 cap 12″ x 14″ x 14′ 00″. 1 sill 12″ x 12″ x 20′ 00″. 4 posts 12″ x 12″ x 18′ 00″. 2 braces 3″ x 10″ x 26′ 00″.	2 stringers 10″ x 16″ x 28′ 00″. 2 guard pcs. 3″ x 10″ x 16′ 00″. 4 braces 3″ x 10″ x 20′ 00″.
IRON			
8 dowel pins 1″ x 10″ long. 20 drift pins ¾″ x 10″ long. 12 bolts ¾″ x 18″ long. 12 nuts for ¾″ bolts. 24 C. I. (ogee) washers.	6 packing bolts ¾″ x 36″. 36 C. I. (ogee) washers. 6 nuts for ¾″ bolts. 8 bolts ¾″ x 18″ long. 16 C. I. (ogee) washers. 8 nuts for ¾″ bolts. 30 wire spikes 6″ long.	8 dowel pins 1″ x 10″ long. 20 drift pins ¾″ x 22″ long. 12 bolts ¾″ x 18″ long. 12 nuts for ¾″ bolts. 24 C. I. ogee washers.	6 packing bolts ¾″ x 36″. 36 C. I. ogee washers. 6 nuts for ¾″ bolts. 8 bolts ¾″ x 18″ long. 16 C. I. washers. 8 nuts for ¾″ bolts. 30 wire spikes 6″ long.

TIMBER

Bent, 24 feet high	Bay, 13-foot centers	Bent, 30 feet high	Bay, 13-foot centers
1 cap 12″ x 14″ x 14′ 00″. 1 sill 12″ x 12″ x 22′ 00″. 4 posts 12″ x 12″ x 24′ 00″. 2 sashes 3″ x 10″ x 16′ 00″. 2 braces 3″ x 10″ x 18′ 00″. 2 braces 3″ x 10″ x 22′ 00″.	2 stringers 10″ x 16″ x 28′ 00″. 2 guard pcs. 3″ x 10″ x 16′ 00″. 8 braces 3″ x 10″ x 18′ 00″. 2 girts 4″ x 10″ x 16′ 00″.	1 cap 12″ x 14″ x 14′ 00″. 1 sill 12″ x 12″ x 24′ 00″. 4 posts 12″ x 12″ x 28′ 00″. 2 sashes 3″ x 10″ x 16′ 00″. 2 braces 3″ x 10″ x 22′ 00″. 2 braces 3″ x 10″ x 24′ 00″.	2 stringers 10″ x 16″ x 28′ 00″. 2 guard pcs. 3″ x 10″ x 16′ 00″. 8 braces 3″ x 10″ x 18′ 00″. 2 girts 4″ x 10″ x 16′ 00″.

IRON

8 dowell pins 1″ x 10″ long. 20 drift pins ¾″ x 22″ long. 20 bolts ¾″ x 18″ long. 4 bolts ¾″ x 21″ long. 24 nuts for ¾″ bolts. 48 C. I. (ogee) washers. 20 wire spikes 6″ long.	6 bolts ¾″ x 36″ long. 16 bolts ¾″ x 18″. 4 bolts ¾″ x 9″. 2 bolts ¾″ x 25″. 60 C. I. (ogee) washers. 28 nuts for ¾″ bolts. 50 wire spikes 6″ long.	8 dowell pins 1″ x 10″ long. 20 drift pins ¾″ x 22″ long. 20 bolts ¾″ x 18″ long. 4 bolts ¾″ x 21″ long. 24 nuts for ¾″ bolts. 48 C. I. ogee washers. 20 wire spikes 6″ long.	6 bolts ¾″ x 36″ long. 16 bolts ¾″ x 18″. 4 bolts ¾″ x 9″. 2 bolts ¾″ x 25″. 60 C. I. ogee washers. 28 nuts for ¾″ bolts. 50 wire spikes 6″ long.

TABLE XLII.—*Standard gauge railway—Bill of materials for timber trestle bridges*—Continued

TIMBER

Bent, 60 feet high	Bay, 13-foot centers	Bent, 66 feet high	Bay, 13 foot-center
1 pc. 12″ x 14″ x 14′ 00″. 1 pc. 12″ x 12″ x 14′ 00″. 2 pcs. 12″ x 12″ x 20′ 00″. 1 pc. 12″ x 12″ x 26′ 00″. 15 pcs. 12″ x 12″ x 20′ 00″. 4 pcs. 3″ x 10″ x 14′ 00″. 8 pcs. 3″ x 10″ x 16′ 00″. 4 pcs. 3″ x 10″ x 18′ 00″. 8 pcs. 3″ x 10″ x 20′ 00″. 2 pcs. 3″ x 10″ x 28′ 00″.	2 pcs. 10″ x 16″ x 28′00″. 2 pcs. 3″ x 10″ x 16′ 00″. 10 pcs. 6″ x 10″ x 16′ 00″. 8 pcs. 3″ x 10″ x 14′ 00″. 24 pcs. 3″ x 10″ x 18′ 00″.	1 pc. 12″ x 14″ x 14′ 00″. 1 pc. 12″ x 12″ x 14′ 00″. 1 pc. 12″ x 12″ x 20′ 00″. 1 pc. 12″ x 12″ x 22′ 00″. 1 pc. 12″ x 12″ x 28′ 00″. 15 pcs. 12″ x 12″ x 22′ 00″. 2 pcs. 3″ x 10″ x 14′ 00″. 2 pcs. 3″ x 10″ x 16′ 00″. 8 pcs. 3″ x 10″ x 18′ 00″. 4 pcs. 3″ x 10″ x 20′ 00″. 8 pcs. 3″ x 10″ x 22′ 00″. 2 pcs. 3″ x 10″ x 28′ 00″.	2 pcs. 10″ x 16″ x 28′ 00″. 2 pcs. 3″ x 10″ x 16′ 00″. 10 pcs. 6″ x 10″ x 16′ 00″. 8 pcs. 3″ x 10″ x 14′ 00″. 24 pcs. 3″ x 10″ x 18′ 00″.

IRON

30 dowel pins 1″ x 10″ long. 64 drift pins ¾″ x 22″ long. 40 bolts ¾″ x 18″ long. 39 bolts ¾″ x 21″ long. 80 nuts for ¾″ bolts. 160 c. i. ogee washers. 80 wire spikes 6″ long.	14 bolts ¾″ x 36″ long. 64 bolts ¾″ x 18″. 12 bolts ¾′ x 9″. 2 bolts ¾″ x 25″. 92 nuts for ¾″ bolts. 208 c. i. ogee washers. 150 wire spikes 6″ long.	30 dowel pins 1″ x 10″ long. 64 drift pins ¾″ x 22″. 40 bolts ¾″ x 18″. 39 bolts ¾″ x 21″. 80 nuts for ¾″ bolts. 160 c. i. ogee washers. 80 wire spikes 6″ long.	14 bolts ¾″ x 36″ long. 64 bolts ¾″ x 18″ long. 12 bolts ¾″ x 9″ long. 2 bolts ¾″ x 25″ long. 92 nuts for ¾″ bolts. 208 c. i. washers. 150 wire spikes 6″ long.

TIMBER

Bent, 72 feet high	Bay, 13-foot centers	Bent, 78 feet high	Bay, 13-foot centers
1 pc. 12″ x 14″ x 14′ 00″.	2 pcs. 10″ x 16″ x 28′ 00″.	1 pc. 12″ x 14″ x 14′ 00″.	2 pcs. 10″ x 16″ x 28′ 00″.
1 pc. 12″ x 12″ x 16′ 00″.	2 pcs. 3″ x 10″ x 16′ 00″.	1 pc. 12″ x 12″ x 16′ 00″.	10 pcs. 6″ x 10″ x 16′ 00″.
2 pcs. 12″ x 12″ x 22′ 00″.	10 pcs. 6″ x 10″ x 16′ 00″.	1 pc. 12″ x 12″ x 22′ 00″.	8 pcs. 3″ x 10″ x 14′ 00″.
1 pc. 12″ x 12″ x 30′ 00″.	8 pcs. 3″ x 10″ x 14′ 00″.	1 pc. 12″ x 12″ x 24′ 00″.	2 pcs. 3″ x 10″ x 16′ 00″.
15 pcs. 12″ x 12″ x 24′ 00″.	24 pcs. 3″ x 10″ x 18′ 00″.	1 pc. 12″ x 12″ x 30′ 00″.	24 pcs. 3″ x 10″ x 18′ 00″.
2 pcs. 3″ x 10″ x 16 ′00″.		15 pcs. 12″ x 12″ x 26′ 00″.	
2 pcs. 3″ x 10″ x 18′ 00″.		2 pcs. 3″ x 10″ x 12′ 00″.	
8 pcs. 3″ x 10″ x 20′ 00″.		5 pcs. 3″ x 10″ x 16′ 00″.	
4 pcs. 3″ x 10″ x 22′ 00″.		2 pcs. 3″ x 10″ x 18′ 00″.	
8 pcs. 3″ x 10″ x 24′ 00″.		10 pcs. 3″ x 10″ x 20′ 00″.	
2 pcs. 3″ x 10″ x 30′ 00″.		2 pcs. 3″ x 10″ x 22′ 00″.	
		10 pcs. 3″ x 10″ x 24′ 00″.	

IRON

30 dowel pins 1″ x 10″ long.	14 bolts ¾″ x 36″ long.	30 dowel pins 1″ x 10″ long.	14 bolts ¾″ x 36″ long.
64 drift pins ¾″ x 22″ long.	64 bolts ¾″ x 18″.	64 drift pins ¾″ x 22″ long.	64 bolts ¾″ x 18″.
40 bolts ¾″ x 18″ long.	12 bolts ¾″ x 9″.	40 bolts ¾″ x 18″ long.	12 bolts ¾″ x 9″.
39 bolts ¾″ x 21″ long.	2 bolts ¾″ x 25″.	39 bolts ¾″ x 21″ long.	2 bolts ¾″ by 25″.
80 nuts for ¾″ bolts.	92 nuts for ¾″ bolts.	80 nuts for ¾″ bolts.	92 nuts for ¾″ bolts.
160 c. i. ogee washers.	208 c. i. ogee washers.	160 c. i. washers.	208 c. i. ogee washers.
80 wire spikes 6″ long.	150 wire spikes 6″ long.	80 wire spikes 6″ long.	150 wire spikes 6″ long.

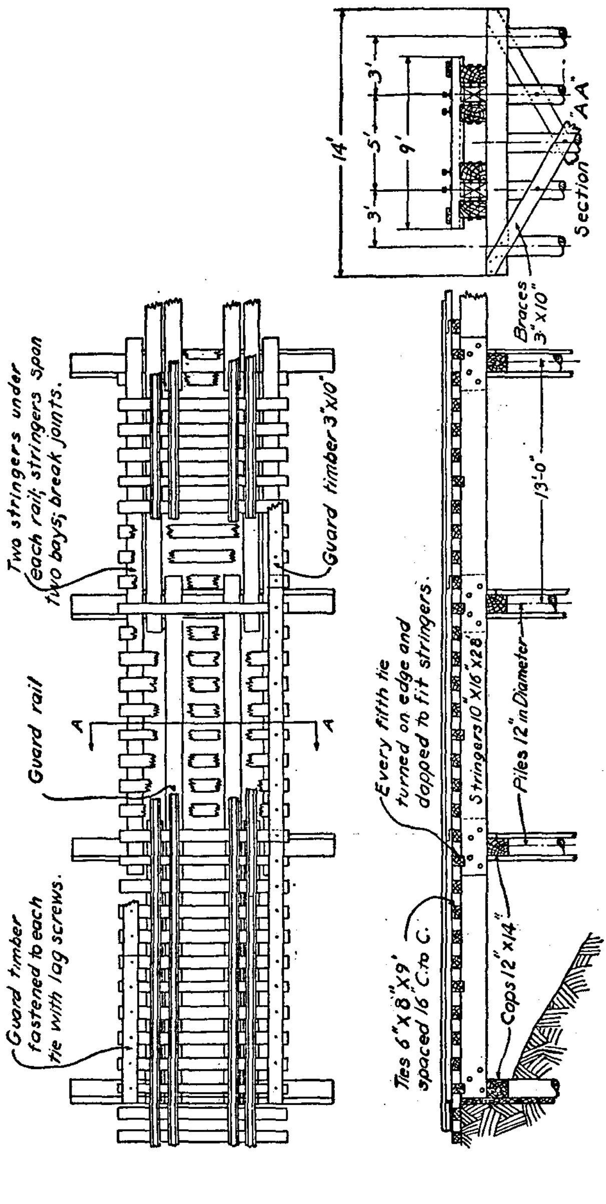


FIGURE 81.—Floor system for standard gauge railway timber or pile trestle

TABLE XLIII.—*Standard gauge railway—Bill of materials for pile bridges*

(Span 13 feet C-C of bents)

Details	One span	Each additional span
Piles:		
End bents	10	
Intermediate bents		5
Caps, 12 by 14 inches by 14 feet	2	1
Sway braces, 3 by 10 inches (length depends on height of bent)		2
Stringers, 10 by 16 inches:		
15 feet long	4	[1] 4
28 feet long		[2] 4
Ties, 6 by 8 inches by 9 feet	10	10
Guard timbers, 3 by 10 inches by 15 feet	2	2
Stringer bolts, square heads and nuts, ¾-inch diameter, 39 inches long	12	8
Lag screws, for guard timbers	20	20
Sway brace bolts, square heads and nuts, ¾-inch diameter, 3½ inches threaded, 18 inches long		10
Packing spools	12	16
Washers		10
Drift bolts, ¾-inch diameter, 22 inches long	8	6
Bulkheads:		
Planks 4 by 12 inches by 16 feet	10	
Spikes 10 inches long	50	

[1] For a single span. [2] For each 2 spans.

144. Yards.—A yard consists of a number of sidings and spurs usually parallel to each other, although often not parallel to the main track. The tracks must be sufficient in number to permit the convenient and rapid breaking up of trains, classification of cars by contents, destination or otherwise, and making them up into new trains in accordance with the new requirements. Yard tracks are divided into groups according to their purpose. A certain number near the main line at one end of the yard are called receiving tracks and constitute the receiving yard where the arriving trains pull in. In convenient proximity are caboose tracks where cabooses are stored when not in trains. A group of repair tracks are convenient to the receiving yard. An engine lead track is provided for moving engines from the receiving yard to the engine terminal, which includes cinder pit tracks, a coaling station, an engine house, a turntable or wye track or loop for turning engines around, a water station and engine-ready tracks, where the engines are stored after they have been made ready for service. A train from the receiving yard is pushed slowly over a hump track, the cars being uncoupled at the summit of the hump and drifted by gravity into a second group of tracks called the classification yard. In yards where there is no hump the switch engine pushes the cars on to the classification tracks. Cars to be repaired are drifted by gravity into the repair yard. From the classification yard, cars are moved into a group of tracks called the forwarding yard, where the cars are inspected and made ready for forwarding out of the terminal. Usually a terminal is arranged for classification in one direction only, which direction is determined by the current of traffic. In most cases it is sufficient to provide a simple parallel yard for the movement in the opposite direction, usually called an empty yard. All yard tracks should be double ended tracks so that traffic may move through a terminal in one direction which saves confusion and delay. The yard layout described in this paragraph is illustrated in Figure 74. When it is necessary to develop new yards for military purposes, the essential features described above should be provided. In order that the urgent needs may be immediately met, the development of the yards proceeds somewhat as follows assuming the preponderance of the traffic to be moving in a west to east direction: Eastbound receiving yards, first installation—3 tracks, more to be added as necessity develops; eastbound classification yard, first installation—8 tracks, more to be added as necessity develops; when conditions warrant the necessary construction, a hump between receiving and classification yard, a by-pass around the hump to be added when practicable; eastbound departure yard and another classification yard will be added later to meet demands, the tracks being added as necessity develops. At first, one receiving yard and one classification yard can be used for receiving, classifying, and departure in both directions. Westbound receiving and departure yards may be used should the necessity for westbound traffic develop. It depends on the location and conditions whether one yard with many tracks is to be used for receiving and classifying or whether the tracks are to be divided into 2 yards. Within the leads the tracks should be from 1,500 to 2,000 feet long. Ballasting is not done until it is demonstrated to be absolutely necessary.

145. Signal communication.—A system of signal communication is essential for the operation of the railway. This may be either a telegraph or telephone system, the telephone being preferred because it can be operated by anyone without special training. The wire circuits should be at the exclusive disposal of the railway. Where the railways must use the military signal communication system, it is essential that one or more wires be assigned exclusively to the railroad service and that no nonrailroad messages be put on these wires. To facilitate operation telephones should be connected at all sidings to enable trainmen out on the line to communicate directly with the train dispatcher.

146. Regulating stations.—*a. Purpose.*—A regulating station is an agency in the system of supply for the field forces which directs and controls the movements of troops and materials by rail to or from the area which it is specifically designated to serve (usually one army area). The traffic beyond the regulating station up to the railheads consists of a number of standard carloads of maintenance articles per day per military division at the front, plus any special requirements, all exclusive of ammunition which is sent in special trains from advance ammunition depots. A regulating station may be called upon to send on short notice a replacement of a daily train which may have failed to reach its railhead because of accident, enemy interference or other reason. In order to be able to comply with such emergency demands, a number of tracks are set aside at the regulating station on which a few loaded standard trains are held for immediate forwarding. Although not strictly a function of a regulating station it was found necessary toward the close of the World War to provide a small amount of storage at these stations for commodities known as regulating station reserves, to safeguard against any breakdown in the lines of communication.

b. Facilities.—The facilities required at a regulating station consist of a railway yard with receiving, classification and departure tracks, tracks for loaded emergency trains (rolling reserves), limited storage space for regulating station reserves, a small warehouse with transfer platforms to facilitate the handling of less-than-carload shipments, barracks, mess halls and hospitals for handling casual transients, and facilities for detraining and resting animals. Engine terminal facilities are also necessary. A regulating station serving one field army should have at least 25 yard tracks, each approximately 1,500 to 2,000 feet in length.

c. Location.—The regulating station should be located at a point where the main line from the rear branches into several lines running to the front and should be upon, or have access to, a belt line permitting rail movements through the regulating station to be routed laterally along the front when required by the military situation. A point where existing railway facilities

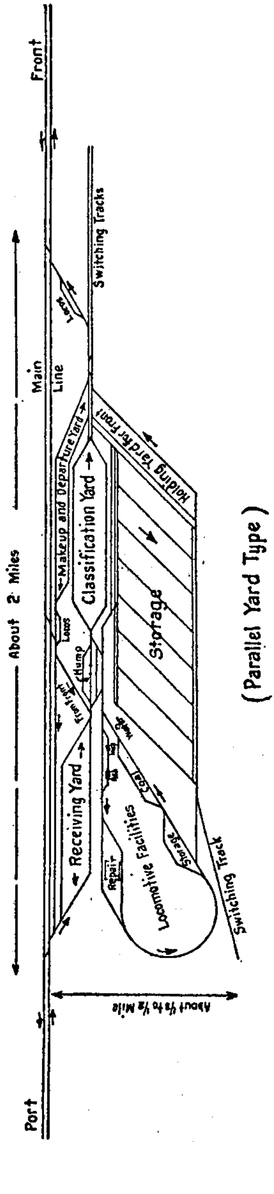


FIGURE 82.—Schematic plan of a typical regulating station layout

are ample is usually selected for use as a regulating station in order to avoid, if possible, any new railway construction. An existing terminal is, in most cases, suitable for a regulating station, although the necessary shelter and storage facilities may have to be constructed.

d. Layouts.—Figure 82 shows a typical layout of a regulating station.

147. Railheads.—A railhead is a point on the railroad in the theater of operations at which supplies for troops are discharged, and from which they are distributed or forwarded to relay, refilling or distributing points. It may consist of a highly organized railway station with sidings and storehouses, or it may be merely a place where the railway runs near a highway where supplies are transferred to the vehicles of organizations. Normally, it consists of some installation between these two extremes. The railhead is generally chosen so as to utilize existing rail facilities. The question of what facilities are necessary depends upon whether the railhead is to serve one or more large units (division, corps, or army troops) and whether it is to be used simply for the receipt of daily automatic supplies of food and fuel, or whether large amounts of supplies such as engineer materials and ammunition are to be received. In a case where a railhead is serving a single division with daily automatic supplies only the essential facilities include a siding long enough to accommodate the daily train, ample roadways for approach and departure, space for accommodating the organizational vehicles while loading, and parking space for waiting vehicles. If the situation be such that it is impracticable to transfer the daily supplies directly from the railway cars to the organization vehicles, the railhead should include some sort of storage facility to accommodate a limited quantity of stores for emergency use and one or more days' supply of rations, forage, fuel, and other articles of approximately uniform daily consumption from which supply columns or field trains of the combat troops may be filled without holding them for the arrival of the railway trains. In this case a warehouse

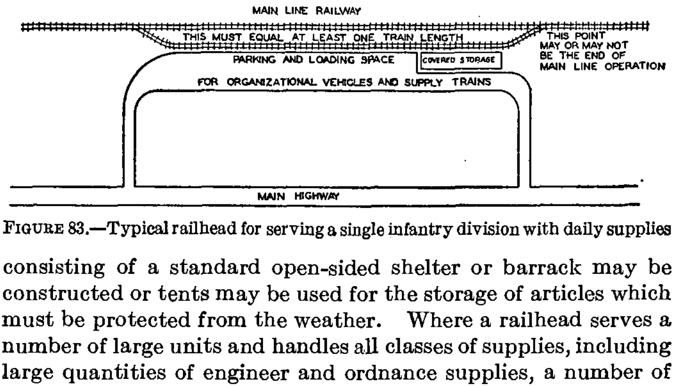


FIGURE 83.—Typical railhead for serving a single infantry division with daily supplies

consisting of a standard open-sided shelter or barrack may be constructed or tents may be used for the storage of articles which must be protected from the weather. Where a railhead serves a number of large units and handles all classes of supplies, including large quantities of engineer and ordnance supplies, a number of ladder or spur tracks may be necessary, and these may have to be constructed. The organization of the railhead may also require in this case the construction of a considerable amount of roads to enable the organization vehicles and supply trains to have access to the railway cars and storage places. A typical railhead is shown in Figure 83.

SECTION II

RECONNAISSANCE

148. Initial reconnaissance.—Upon entering a new theater of operations a comprehensive reconnaissance of the railway situation is made at once, and an early report of the condition and capacity of the existing facilities is made in order to permit intelligent planning by the tactical staffs. The first reconnaissance of the railroad need not be extensive, but should aim at discovering quickly the general condition and capacities of the roadbed, track, motive power, cars, and terminal facilities, and an estimate of the amount and kind of engineer work necessary to render the facilities serviceable for the immediate needs of the military force. This information is gained from every available source, including airplane photographs, reports of reconnaissance detachments (of all arms), interrogation of civilian employees of the railway lines, files of the railway offices, and personal reconnaissances by the unit engineer and his assistants. In making this hasty reconnaissance, the following are the principal points to be noted: The gauge of the line; whether the line is passable throughout, and if not, at what points and for what reason stoppages of traffic would occur; the actual number and nature of engines and cars available; the location and length of trackage at stations and other points where troops and impedimenta may be entrained and detrained; and stocks of fuel and railway maintenance material on hand. The capacity of the line and the terminals should be expressed in terms of trains per day, as explained in paragraph 151.

149. Detailed reconnaissance.—After the military authorities have taken over the control of operations of an existing railway line, a complete and detailed survey is made of the facilities. This survey is for the purpose of informing the unit engineer of all the facts pertinent to the operation and maintenance of the line, and should cover in detail the following points: Local name of the railway; terminal points and distances between stations and other points; gauge; single, double or multiple track; condition of roadbed, ties, and rails; ruling grade and maximum curvature; number, length, and location of passing tracks; location of grade crossings; drainage and liability to overflows or washouts; facilities for repair; condition of right of way for marching troops along the line; number, location, dimensions, and strength of tunnels and bridges; number and nature of engines and cars; available capacity for transporting troops and supplies between given points; location and capacity of shops and store yards; name and location of stations with facilities for entraining and detraining troops; sidings; platforms; ramps; turntables; water tanks; fuel supply; storage facilities; derricks or cranes; signal communications. This reconnaissance is usually made under the direction of the commander of the engineer railway troops who are to operate and maintain the line. The data once obtained are kept current by periodic reports.

150. Captured railways.—A reconnaissance of railway lines captured from the enemy presents a special problem, since the enemy in his retirement cripples the railway as far as he possibly can. A reconnaissance party is sent ahead to determine the condition of the line, the repairs necessary to make it passable, and the location of all materials which can be used in repairing the line. This information is sent back at frequent intervals in fragmentary reports rather than awaiting completion of the reconnaissance, in order that the troops in the rear may push forward the operation of the line as far as possible at an early moment. Special attention should be given to the possibility of delayed action mines placed in culverts and abutments where bridges have been destroyed. The location of detour lines which could be constructed rapidly should be investigated. Sources of ballast material should be located in order to avoid as far as possible bringing up ballast from the rear.

151. To determine the capacity of railways.—*a. Main line.*—The capacity of a single track main line for military purposes should be expressed in terms of the feasible movement of trains per day, thus, "six 30-car trains per day, each way between *X* and *Y*. These trains must not be loaded in excess of 1,500 tons." The capacity of the line as thus expressed is fixed by the speed of operation under the existing physical conditions and characteristics of the line and by the length of the existing passing tracks which fix the number of cars per train. Under military conditions the range of capacity of a line is generally about as follows: A single track line in good condition with a ruling grade of one per cent and passing tracks at 6 to 10 mile intervals may conservatively be depended upon for the passage of 10 trains each way per 24 hours, the maximum length of the trains being fixed by the clear length of the sidings and the maximum tonnage not exceeding 1,500 tons. Where the ruling grade is in excess of one per cent, the number of trains per day would not necessarily differ from this estimate, since the tonnage of trains can be reduced to meet the demands of increased grade; however, the ton-mileage over the line will probably be reduced. On double track line the ton-mileage is affected by the grade, as in the case of single track, but the number of trains dispatched over the line per day is usually not dependent upon the main line but upon the facilities for dispatching and receiving trains at the terminals.

b. Terminals.—Experience has shown that the capacity of a railroad terminal in terms of cars passing through the terminal per 24 hours can be expressed by the total lengths of trackage in either the receiving or classification yards, which are usually of approximately the same size. Therefore, to determine the capacity of a given terminal on reconnaissance, measure the total length of track in either the receiving or classification yard in feet, divide by the average length of cars to get the approximate car capacity of the yard, and assume that two-thirds this number of cars can be handled through the terminal each 24 hours.

c. Entraining stations, railheads and depots.—The capacity of entraining points, railheads, and depots should be expressed in terms of loading and unloading possibilities, thus, "The capacity of Station B permits the simultaneous loading and unloading of 15 trains of approximately 25 cars each on side tracks without interfering with main-line operations."

152. To determine gradient.—A reconnoitering officer should locate the ruling grade by observing the action of a track motor car or locomotive in traversing the territory. If it is impractical to make such observations, it will be necessary for him to decide for himself from observation as to where the ruling grade lies. A quick way of roughly determining the per cent of grade is by means of a hand level. Thus, if the observer's height of eye (H. I.) is known to be 5 feet and the hand level projects his level line of vision a distance of 250 feet and there intersects the track, the grade is $\frac{5}{250}=\frac{1}{50}=2$ per cent.

153. To find the degree of curvature.—To find the degree of curve take a cord 62 feet long, knot at the middle, and stretch this cord between the two points on the gauge line of the outer rail. With a rule measure the middle ordinate between the cord and the gauge line at the knot. The length of this ordinate in inches equals the curvature of the track in degrees.

154. To determine the capacity of cars.—The capacities of rolling stock are determined on reconnaissance by inspection of the data usually stenciled on the outside of the cars. The most important data to obtain are the capacity in pounds and in cubic feet. The data should be compiled by car numbers in series as far as practicable.

155. To estimate the capacity of railway bridges.—*a. Cooper's rating.*—It has become the custom of many railroads to specify Cooper's Standard Loadings as the basis of bridge design. This is a standard loading representing approximately the average locomotives in use. Figure 84 shows the Cooper's E–60 loading.

Other loadings are designated as E–50, E–40, etc., these differing from the E–60 type in that the loads are proportionately less, the number and spacing of the axles remaining the same. As there is usually an economic consistency throughout the design of all parts of a bridge, the dimensions of the floor system give a clue to the loading which was probably used in the design of the whole structure. Table XLIV shows the Cooper's E rating of a number of typical railway bridges and the dimensions of the stringers of their floor systems. When it is desired to estimate the capacity of any existing railway bridge it is simply necessary to measure with a foot rule the width and thickness of the lower flange of the

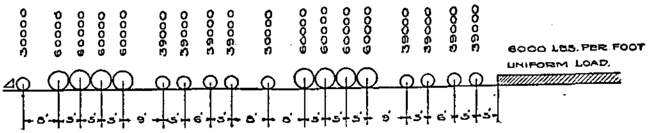


FIGURE 84.—Cooper's standard E–60 loading

stringer or girder at the center, the depth of the stringer, and its length, find in the table the stringer most nearly approximating these dimensions, and read off the probable E rating of the bridge.

b. Passage of railway artillery.—The military engineer may be called upon to give an opinion of the feasibility of using a given bridge for the passage of railway artillery. Railway artillery mounts producing equivalent bridge stresses have been given Cooper's E ratings. Having determined the probable rating of the bridge by the above method, a comparison with the rating of the artillery carriage will be an aid to the judgment. It should be remembered that most bridges are designed with a considerable factor of safety, and for high impact. It is therefore probable that by exercising due caution as to speed and spacing of cars in the train a bridge will pass artillery carriages of considerably higher rating.

TABLE XLIV.—*Reconnaissance of railway bridges*

Bridge capacities expressed in Cooper's "E" rating, as reflected in the dimensions of the stringers of steel truss or open deck girder bridges of various panel lengths

Panel length in feet[1]				10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30	35
Dimensions of stringers in inches[1]																				
Lower flange		Beam depth	Size of angles																	
Thickness	Width																			
3/8	8 3/8	18	4x3x3/8	E-42	E-41	E-41	E-41													
3/8	10 3/8	24	5x3 1/2x3/8		E-59	E-48	E-40	E-35	E-31	E-27										
1/2	10 3/8	30	5x3 1/2x1/2				E-61	E-59	E-51	E-46	E-41	E-37	E-33	E-30	E-27					
1/2	12 1/2	30	6x4x1/2						E-62	E-56	E-50	E-45	E-41	E-37	E-31	E-26				
1	14	36	6x4x1/2								E-60	E-58	E-55	E-54	E-51	E-48	E-43	E-39	E-34	E-26
1/2	12 3/8	42	6x4x1/2										E-60	E-54	E-45	E-39	E-34	E-30	E-26	
1 1/8	14	42	6x4x1/2											E-63	E-60	E-57	E-54	E-51	E-45	
Panel length[1]				28	30	35	40	44	50	54	60	64	70	74	80	84	90	94	100	110
Stringer dimensions[1]																				
1 1/8	16	42	6x6x1/2	E-60	E-54	E-42	E-32													
1 1/2	16	48	6x6x3/4		E-57	E-52	E-47	E-43	E-33											
1	16	48	6x6x1/2	E-66	E-59	E-45	E-35	E-30												
1 5/8	14	54	6x4x5/8			E-54	E-43	E-36	E-28											

1¾	14	60	6x6x½	------	------	------	E-60	E-54	E-43	E-37	E-30	E-27	------	------	------	------	------	------	------	------
1½	14	60	6x6x⅝	------	------	------	E-57	E-48	E-38	E-33	E-27	------	------	------	------	------	------	------	------	------
2⅛	15	66	6x6x⅝	------	------	------	------	------	E-57	E-54	E-46	E-41	E-34	E-31	E-26	------	------	------	------	------
2	14	66	6x6x¾	------	------	------	------	------	E-56	E-48	E-40	E-35	E-30	E-26	------	------	------	------	------	------
2	14	72	6x6x¾	------	------	------	------	------	E-62	E-54	E-44	E-39	E-32	E-29	E-25	------	------	------	------	------
2½	15½	72	6x6x¾	------	------	------	------	------	------	------	E-55	E-51	E-43	E-38	E-33	E-28	------	------	------	------
1⅛	14	78	6x6x¾	------	------	------	------	------	------	E-64	E-52	E-46	E-39	E-35	E-30	------	------	------	------	------
2½	16	84	6x6x¾	------	------	------	------	------	------	------	------	E-64	E-54	E-49	E-41	E-38	E-33	E-30	------	------
2 11/16	20	96	6x6x¾	------	------	------	------	------	------	------	------	------	------	------	------	E-59	E-51	E-46	E-41	E-34

For reinforced concrete slab ballast deck plate girder spans reduce the rating given as follows: For spans 10 feet to 19 feet reduce by 8; for spans 20 feet to 45 feet reduce by 10; 50 feet to 75 feet reduce by 12; 75 feet to 120 feet reduce by 14.

[1] For girder bridge without stringers, use the dimensions of the girder itself.

66684°—32——14

Section III

LOCATION AND CONSTRUCTION

156. General.—*a. Scope.*—The methods of construction of a standard gauge railway line in accordance with the refined standards of civil practice are beyond the scope of this manual. The principles and methods described herein are used in the kind of railway construction commonly undertaken in the combat zone, and in the hasty construction of such railway facilities as additional tracks in yards, at ports, and in military supply installations set up in the communications zone.

b. Summary of steps in construction.—The construction of the roadbed comprises the following steps in order:

(1) A preliminary reconnaissance of the terrain for the selection of the general location of the line.

(2) A survey of the line selected, to obtain topographical data upon which to base the exact location of the line.

(3) A construction survey for setting stakes to give line and grade to the construction party.

(4) The preparation of the subgrade by cuts into, and fills upon the natural ground in order to provide a smooth roadbed for the track.

(5) Unloading and distributing ties along the subgrade.

(6) Spacing ties and placing them in proper alignment.

(7) Unloading and distributing rails.

(8) Unloading and distributing track joint material.

(9) Unloading spikes, bolts, nut locks and nuts at rail joint.

(10) Spiking the line rail at uniform measured distance from end of ties to rail.

(11) Lining the opposite rail to gauge and spiking rail on tie.

(12) Throwing track to approximate alignment as fixed by line stakes.

(13) Blocking up track to a temporary surface with dirt, stone, or other readily available material preparatory to unloading ballast.

(14) Unloading ballast on track.

(15) Jacking track up and tamping ballast under ties.

(16) Repeating operations in 14 and 15 above until the required amount of ballast has been inserted to bring the top of rail to the designated grade.

The foregoing steps are discussed in detail in the following paragraphs.

c. General considerations.—The construction of the line is preceded by a survey in order to select a line involving the least expenditure of time, the easiest gradients, and the minimum of curvature, cuts, fills, and bridges. If maps are available showing the characteristics of the country to be traversed such as contours, rivers, towns, etc., the location of the line can be made directly on the maps, supplemented by personal reconnaissance over the route or routes which appear practicable. If maps are not available a reconnaissance of the ground is made by the locating engineer, either on foot or by horseback, to enable him to select one or more practicable routes. In making his selection he must bear in mind the limitations of the proposed construction with regard to grades and curves.

(1) The maximum allowable grade will be, in general, the governing factor when deciding which of the possible routes will be chosen for further investigation and construction. The line must be so located as to keep the grade within the adopted limit, which will usually be below 2 per cent, although in exceptional cases and for short grades this may be exceeded.

(2) It is usually impracticable definitely to determine what maximum degree of curvature can be used from a mere reconnaissance of a proposed route. However, the locating engineer should satisfy himself that a line can be located with curves not in excess of 10° before adopting any given route.

(3) Natural drainage lines present the most regular and easiest gradients and in a broad sense it may be said that every railroad location follows lines of drainage. When the head or source of one drainage line is reached, the location crosses the divide to the next. With a few exceptions, drainage lines have gradients not exceeding those permissible for railroad location. The first requisite in considering a railroad location is to get these natural routes clearly in mind before undertaking the reconnaissance. Other things being equal, the shortest route between the initial point and the objective is the line to be followed, but consideration of excessive grade and construction difficulties may outweigh the advantage of shortness.

157. Railway curves.—*a. Definition.*—A line of railway is made up of curved and straight lengths. The former are called curves and the latter tangents. Railroad curves are usually arcs of circles. They may be either simple, compound, or reverse. A simple curve is a curve with a constant radius. A compound curve is one composed of two or more simple curves of different radii curving in the same direction and having a common tangent at their point of meeting. A reverse curve is composed of two simple curves curving in opposite directions and having a common tangent at their point of meeting. The name is also commonly applied to two simple curves curving in opposite directions, which are joined by a tangent shorter than the usual length of trains running on the line. A transition or easement curve is a compound curve, or spiral, used at the ends of a sharp curve to lead gradually from the tangent to the main curve. For the hasty railway installations coming within the scope of this manual

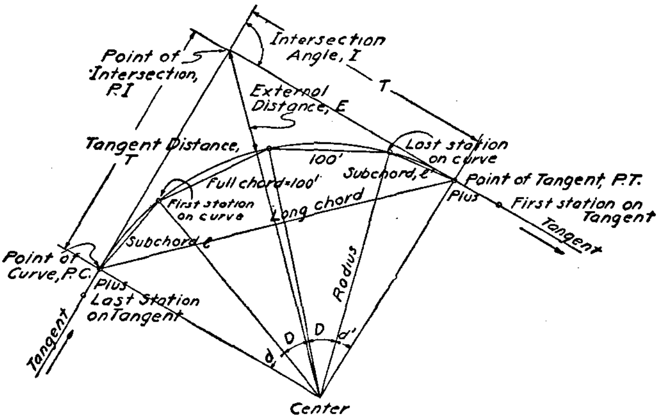


FIGURE 85.—Elements of simple curve

where high speed operation is not contemplated, transition curves are not employed.

b. Elements of a curve.—(1) A curve is measured along its chords, and such length of chord should be used that the ratio of the arc to the corresponding chord is practically unity. The number of subtending chords multiplied by the length of such chords is called the length of the curve, *l*. In general 100-foot chords are used and as a curve would not ordinarily comprise a round number of 100-foot chords, chords of less than 100 feet, called subchords, are introduced, usually one at the beginning and one at the end of the curve.

(2) When a chord of 100 feet subtends an angle of 1° at the center the curve is said to be a 1° curve. Within the range of curvature used in railroad construction the elements of the curve are approximately inversely proportional to the degree of curve,

D, and having the elements for the curvature of 1°, those for any other curvature may be obtained by dividing the quantity for 1° by the desired value of D. Table XLV gives the elements for a curvature of 1°. To obtain the elements for any other curvature, take out the quantities from Table XLV for some central angle and divide them by D.

(3) It is desirable to have the number of the station at any point indicate the total length of the line to that point, and hence in passing from curve to tangent, or from tangent to curve, there should be 100 feet between the last station on the one and the first station on the other. If the point of curve, *PC*, is at a fractional station on a tangent—called a "plus"—the curve should begin with a subchord equal to the difference between 100 feet and the plus. If the point of tangent, *PT*, is at a plus, or the curve ends with a subchord, the first station on the tangent will be at a distance from *PT* equal to 100 feet less the length of the subchord. Only in rare cases will the *PC* fall on a station of the tangent and the curve be a number of hundreds of feet in length, hence we usually find a subchord at each end of a curve.

(4) The angle between a chord or subchord and a tangent to the circle at one of its ends is measured by one-half of the arc corresponding to the chord or subchord. The angle between a chord or subchord and a secant, or the angle between two secants intersecting on an arc, is measured by one-half the difference of the arcs subtended by the chords or secants.

(5) With equal chords of 100 feet, as in railroad practice, the arc corresponding to a chord is D, the degree of curvature; and the difference of the arcs corresponding to a chord or subchord and the secant to the first station beyond it, or between the secants to adjacent stations, is also D. Hence the angle between tangent and chord, or between chord and the secant to the next station beyond it, or between secants to adjacent stations, is $\frac{1}{2}D$. This is called the deflection angle and is very important in curve location.

(6) For simple curves the angle at any station between any other two in the same direction is $\frac{1}{2}D\times(n'-n)$; in which n' is the serial number of the farther and n of the nearer station. For example, the angle at station 12 between station 17 and 22$=$ $\frac{1}{2}D\times(22-17)=2\frac{1}{2}D$.

(7) The deflection angle for any subchord is proportional to the length of the subchord, or is $\frac{1}{2}D\frac{l}{100}$; in which l is the length of the subchord in feet, and generally the angle at any point of the curve between any two other points in the same direction is $\frac{1}{2}D\times\frac{l}{100}$; in which l is the aggregate length of chords and subchords in feet between the two points. The deflection angle of the long chord is $\frac{1}{2}\Delta$, which relation is valuable as a check and should always be so used.

c. Laying out curves.—If at the *PC* an angle of $\frac{1}{2}D\frac{l}{100}$ is measured from the tangent in the direction of curvature, the line of sight passes through the first station beyond the *PC* and if the length l is measured on this line from *PC*, the station is determined. If, now, another or an additional angle of $\frac{1}{2}D$ is measured, the line of sight passes through the next station, and if a 100-foot tape is stretched from the previous station and its forward end swung until it is on this line, the point so determined is the next station. Similarly, any station may be located. The above-described method of determining the chords and subchords of a simple curve is called location by deflections. It is the usual method and is always employed for curves of two or more stations, unless there is something to prevent.

d. Practical layout of a curve.—The general case will be that in which two tangents already located are to be connected by a curve. The steps in running in the curve are as follows:

First step.—Run the tangents out to their intersection, if it has not already been done, and measure the external angle or difference of azimuth, which is Δ.

Second step.—Chain or pace over the ground on which it is desired to locate the curve, determine its approximate length in feet, and point off two places from the right, which gives the length in stations. If a map is available, this distance may be scaled. Divide Δ by this number and the quotient will be *D*. If this is not a convenient degree of curve to use, take the nearest one above or below it and divide it into Δ for the corrected length in stations.

Third step.—Take from Table XLV the tangent distance, T, corresponding to Δ; divide it by D, which gives the tangent distance of the curve, or the distance of PC and PT from V. Locate PC and PT on their respective tangents by measuring back from PI. Measure from PC back to the next preceding station to determine the plus. Begin the curve with a subchord equal to the difference between 100 feet and the plus.

Fourth step.—Compute and tabulate all the deflections from the PC thus:

The deflection

for the first subchord $=\frac{1}{2} D \frac{l}{100}$.

for the first chord $=\frac{1}{2} D \frac{l}{100}+\frac{1}{2} D$.

for the second chord $=\frac{1}{2} D \frac{l}{100}+D$.

for the third chord $=\frac{1}{2} D \frac{l}{100}+1\frac{1}{2} D$.

for the fourth chord $=\frac{1}{2} D \frac{l}{100}+2 D$.

for the last subchord $=\frac{1}{2} D \frac{l}{100}+\frac{n}{2} D+\frac{1}{2} D \frac{l'}{100}=\frac{1}{2}\Delta$.

In the above tabulation l and l' represent the lengths of the first and last subchords in feet, and n the number of 100-foot chords in the curve.

Fifth step.—Set up the transit on PC, put the 0°–180° line on the tangent and turn off in the proper direction the first tabulated angle. Measure on this line the length of the first subchord and locate the first station of the curve. Turn off, from the tangent also, the second tabulated angle and locate the second station by swinging a 100-foot tape from the first station. Continue as long as the stations can be seen clearly from PC. If all can not be seen, shift the transit forward and set on a station which has been determined, and orient by the following rule:

Set the vernier at the reading in the tabulated deflections corresponding to any convenient preceding station, point to that station and clamp the limb. Plunge the telescope and locate forward stations by using the tabulated deflections originally computed for those stations, precisely as if still working from PC. In using this rule remember that the deflection corresponding to PC is the azimuth of the back tangent from which the deflections were started.

Usually the forward tangent will not have been run out much beyond *PT*. Measure off on it from *PT* a distance equal to 100 feet minus the last subchord of the curve, and locate the station next to the curve on the tangent. From this run out the tangent, setting stations 100 feet apart until another curve is reached.

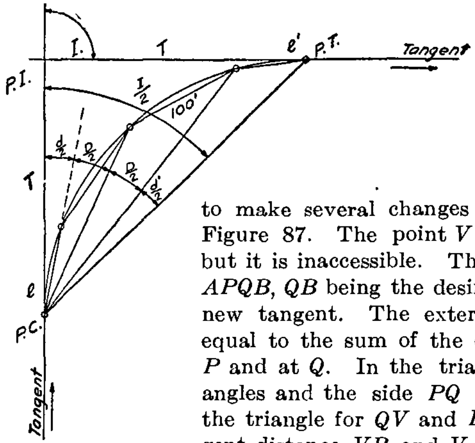


FIGURE 86.—Layout of simple curve by deflection angles

When the *PI* is inaccessible, it may be necessary to make several changes of direction, as in Figure 87. The point *V* would be the *PI*, but it is inaccessible. The line is run along *APQB*, *QB* being the desired direction of the new tangent. The external angle is then equal to the sum of the deflection angles at *P* and at *Q*. In the triangle, *QPV* all the angles and the side *PQ* are known. Solve the triangle for *QV* and *PV*. Find the tangent distance *VB* and *VA*, and lay off from *Q*, *QB* equal to *VB* minus *VQ*; and from *P*, a distance equal to *VA* minus *VP*. The points *B* and *A* thus located are the *PT* and *PC*, respectively. The curve is then laid out as heretofore described.

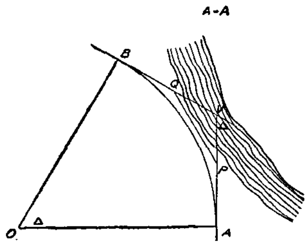


FIGURE 87.—Point of intersection inaccessible

As errors will creep into the location of a curve if very long lines of sight are used in laying out the curve, it is customary not to lay out more than from four to six stations from one point; therefore, on curves longer than this two or more settings of the instrument will be necessary.

TABLE XLV.—*Elements of a circular curve of 1° curvature, 5,730-foot radius*

Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.
° '				° '			
1 00	50.00	0.218	100.00	9 00	450.93	17.717	899.09
10	58.34	0.297	116.67	10	459.32	18.381	915.70
20	66.67	0.388	133.33	20	467.71	19.058	932.31
30	75.01	0.491	150.00	30	476.10	19.746	948.92
40	83.34	0.606	166.66	40	484.49	20.447	965.53
50	91.68	0.733	183.33	50	492.88	21.161	982.14
2 00	100.01	0.873	199.99	10 00	501.28	21.886	998.74
10	108.35	1.024	216.66	10	509.68	22.624	1015.35
20	116.68	1.188	233.32	20	518.08	23.375	1031.95
30	125.02	1.364	249.98	30	526.48	24.138	1048.54
40	133.36	1.552	266.65	40	534.89	24.913	1065.14
50	141.70	1.752	283.31	50	543.29	25.700	1081.73
3 00	150.04	1.964	299.97	11 00	551.70	26.500	1098.3
10	158.38	2.188	316.63	10	560.11	27.313	1114.9
20	166.72	2.425	333.29	20	568.53	28.137	1131.5
30	175.06	2.674	349.95	30	576.95	28.974	1148.1
40	183.40	2.934	366.61	40	585.36	29.824	1164.7
50	191.74	3.207	383.27	50	593.79	30.686	1181.2
4 00	200.08	3.492	399.92	12 00	602.21	31.561	1197.8
10	208.43	3.790	416.58	10	610.64	32.447	1214.4
20	216.77	4.099	433.24	20	619.07	33.347	1231.0
30	225.12	4.421	449.89	30	627.50	34.259	1247.5
40	233.47	4.755	466.54	40	635.93	35.183	1264.1
50	241.81	5.100	483.20	50	644.37	36.120	1280.7
5 00	250.16	5.459	499.85	13 00	652.81	37.069	1297.2
10	258.51	5.829	516.50	10	661.25	38.031	1313.8
20	266.86	6.211	583.15	20	669.70	39.006	1330.3
30	275.21	6.606	549.80	30	678.15	39.993	1346.9
40	283.57	7.013	566.44	40	686.60	40.992	1363.4
50	291.92	7.432	583.09	50	695.06	42.004	1380.0
6 00	300.28	7.863	599.73	14 00	703.51	43.029	1396.5
10	308.64	8.307	616.38	10	711.97	44.066	1413.1
20	316.99	8.762	633.02	20	720.44	45.116	1429.6
30	325.35	9.230	649.66	30	728.90	46.178	1446.2
40	333.71	9.710	666.30	40	737.37	47.253	1462.7
50	342.08	10.202	682.94	50	745.85	48.341	1479.2
7 00	350.44	10.707	699.57	15 00	754.32	49.441	1495.7
10	358.81	11.224	716.21	10	762.80	50.554	1512.3
20	367.17	11.753	732.84	20	771.29	51.679	1528.8
30	375.54	12.294	749.47	30	779.77	52.818	1545.3
40	383.91	12.847	766.10	40	788.26	53.969	1561.8
50	392.28	13.413	782.73	50	796.75	55.132	1578.3
8 00	400.66	13.991	799.36	16 00	805.25	56.309	1594.8
10	409.03	14.582	815.99	10	813.75	57.498	1611.3
20	417.41	15.184	832.61	20	822.25	58.699	1627.8
30	425.79	15.799	849.23	30	830.76	59.914	1644.3
40	434.17	16.426	865.85	40	839.27	61.141	1660.8
50	442.55	17.066	882.47	50	847.78	62.381	1677.3

TABLE XLV.—*Elements of a circular curve of 1° curvature, 5,730-foot radius*—Continued

Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.
° ′				° ′			
17 00	856.30	63.634	1693.8	25 00	1270.2	139.11	2480.2
10	864.82	64.900	1710.3	10	1279.0	141.01	2496.5
20	873.35	66.178	1726.8	20	1287.7	142.93	2512.8
30	881.88	67.470	1743.2	30	1296.5	144.85	2529.0
40	890.41	68.774	1759.7	40	1305.3	146.79	2545.3
50	898.95	70.091	1776.2	50	1314.0	148.75	2561.5
18 00	907.49	71.421	1792.6	26 00	1322.8	150.71	2577.8
10	916.03	72.764	1809.1	10	1331.6	152.69	2594.0
20	924.58	74.119	1825.5	20	1340.4	154.69	2610.3
30	933.13	75.488	1842.0	30	1349.2	156.70	2626.5
40	941.69	76.869	1858.4	40	1358.0	158.72	2642.7
50	950.25	78.261	1874.9	50	1366.8	160.76	2658.9
19 00	958.81	79.671	1891.3	27 00	1375.6	162.81	2675.1
10	967.38	81.092	1907.8	10	1384.4	164.87	2691.3
20	975.96	82.525	1924.2	20	1393.2	166.95	2707.5
30	984.53	83.972	1940.6	30	1402.0	169.04	2723.7
40	993.12	85.431	1957.1	40	1410.9	171.15	2739.9
50	1001.70	86.904	1973.5	50	1419.7	173.27	2756.1
20 00	1010.29	88.389	1989.9	28 00	1428.6	175.41	2772.3
10	1018.89	89.888	2006.3	10	1437.4	177.55	2788.4
20	1027.49	91.399	2022.7	20	1446.3	179.72	2804.6
30	1036.09	92.924	2039.1	30	1455.1	181.89	2820.7
40	1044.70	94.462	2055.5	40	1464.0	184.08	2836.9
50	1053.31	96.013	2071.9	50	1472.9	186.29	2853.0
21 00	1061.9	97.58	2088.3	29 00	1481.8	188.51	2869.2
10	1070.6	99.15	2104.7	10	1490.7	190.74	2885.3
20	1079.2	100.75	2121.1	20	1499.6	192.99	2901.4
30	1087.8	102.35	2137.4	30	1508.5	195.25	2917.6
40	1096.4	103.97	2153.8	40	1517.4	197.53	2933.7
50	1105.1	105.60	2170.2	50	1526.3	199.82	2949.8
22 00	1113.7	107.24	2186.5	30 00	1535.3	202.12	2965.9
10	1122.4	108.90	2202.9	10	1544.2	204.44	2982.0
20	1131.0	110.57	2219.2	20	1553.1	206.77	2998.1
30	1139.7	112.25	2235.6	30	1562.1	209.12	3014.2
40	1148.4	113.95	2251.9	40	1571.0	211.48	3030.2
50	1157.0	115.66	2268.3	50	1580.0	213.86	3046.3
23 00	1165.7	117.38	2284.6	31 00	1589.0	216.25	3062.4
10	1174.4	119.12	2301.0	10	1598.0	218.66	3078.4
20	1183.1	120.87	2317.3	20	1606.9	221.08	3094.5
30	1191.8	122.63	2333.6	30	1615.9	223.51	3110.5
40	1200.5	124.41	2349.9	40	1624.9	225.96	3126.6
50	1209.2	126.20	2366.2	50	1633.9	228.42	3142.6
24 00	1217.9	128.00	2382.5	32 00	1643.0	230.90	3158.6
10	1226.6	129.82	2398.8	10	1652.0	233.39	3174.6
20	1235.3	131.65	2415.1	20	1661.0	235.90	3190.6
30	1244.0	133.50	2431.4	30	1670.0	238.43	3206.6
40	1252.8	135.36	2447.7	40	1679.1	240.96	3222.6
50	1261.5	137.23	2464.0	50	1688.1	243.52	3238.6

TABLE XLV.—*Elements of a circular curve of 1° curvature, 5,730-foot radius*—Continued

Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.
° ′				° ′			
33 00	1697.2	246.08	3254.6	41 00	2142.2	387.38	4013.1
10	1706.3	248.66	3270.6	10	2151.7	390.71	4028.7
20	1715.3	251.26	3286.6	20	2161.2	394.06	4044.3
30	1724.4	253.87	3302.5	30	2170.8	397.43	4059.9
40	1733.5	256.50	3318.5	40	2180.3	400.82	4075.5
50	1742.6	259.14	3334.4	50	2189.9	404.22	4091.1
34 00	1751.7	261.80	3350.4	42 00	2199.4	407.64	4106.6
10	1760.8	264.47	3366.3	10	2209.0	411.07	4122.2
20	1770.0	267.16	3382.2	20	2218.6	414.52	4137.7
30	1779.1	269.86	3398.2	30	2228.1	417.99	4153.3
40	1788.2	272.58	3414.1	40	2237.7	421.48	4168.8
50	1797.4	275.31	3430.0	50	2247.3	424.98	4184.3
35 00	1806.6	278.05	3445.9	43 00	2257.0	428.50	4199.8
10	1815.7	280.82	3461.8	10	2266.6	432.04	4215.3
20	1824.9	283.60	3477.7	20	2276.2	435.59	4230.8
30	1834.1	286.39	3493.5	30	2285.9	439.16	4246.3
40	1843.3	289.20	3509.4	40	2295.6	442.75	4261.8
50	1852.5	292.02	3525.3	50	2305.2	446.35	4277.3
36 00	1861.7	294.86	3541.1	44 00	2314.9	449.98	4292.7
10	1870.9	297.72	3557.0	10	2324.6	453.62	4308.2
20	1880.1	300.59	3572.8	20	2334.3	457.27	4323.6
30	1889.4	303.47	3588.6	30	2344.1	460.95	4339.0
40	1898.6	306.37	3604.5	40	2353.8	464.64	4354.5
50	1907.9	309.29	3620.3	50	2363.5	468.35	4369.9
37 00	1917.1	312.22	3636.1	45 00	2373.3	472.08	4385.3
10	1926.4	315.17	3651.9	10	2383.1	475.82	4400.7
20	1935.7	318.13	3667.7	20	2392.8	479.59	4416.1
30	1945.0	321.11	3683.5	30	2402.6	483.37	4431.4
40	1954.3	324.11	3699.3	40	2412.4	487.16	4446.8
50	1963.6	327.12	3715.0	50	2422.3	490.98	4462.2
38 00	1972.9	330.15	3730.8	46 00	2432.1	494.82	4477.5
10	1982.2	333.19	3746.5	10	2441.9	498.67	4492.8
20	1991.5	336.25	3762.3	20	2451.8	502.54	4508.2
30	2000.9	339.32	3778.0	30	2461.7	506.42	4523.5
40	2010.2	342.41	3793.8	40	2471.5	510.33	4538.8
50	2019.6	345.52	3809.5	50	2481.4	514.25	4554.1
39 00	2029.0	348.64	3825.2	47 00	2491.3	518.20	4569.4
10	2038.4	351.78	3840.9	10	2501.2	522.16	4584.7
20	2047.8	354.94	3856.6	20	2511.2	526.13	4599.9
30	3057.2	358.11	3872.3	30	2521.1	530.13	4615.2
40	2066.6	361.29	3888.0	40	2531.1	534.15	4630.4
50	2076.0	364.50	3903.6	50	2541.0	538.18	4645.7
40 00	2085.4	367.72	3919.3	48 00	2551.0	542.23	4660.9
10	2094.9	370.95	3935.0	10	2561.0	546.30	4676.1
20	2104.3	374.20	3950.6	20	2571.0	550.39	4691.3
30	2113.8	377.47	3966.3	30	2581.0	554.50	4706.5
40	2123.3	380.76	3981.9	40	2591.1	558.63	4721.7
50	2132.7	384.06	3997.5	50	2601.1	562.77	4736.9

TABLE XLV.—*Elements of a circular curve of 1° curvature, 5,730-foot radius*—Continued

Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ	Tang., T.	Ext. dist., E.	Long chord, L. C.
° ′				° ′			
49 00	2611.2	566.94	4752.1	57 00	3110.9	790.08	5467.9
10	2621.2	571.12	4767.3	10	3121.7	795.24	5482.5
20	2631.3	575.32	4782.4	20	3132.6	800.42	5497.2
30	2641.4	579.54	4797.5	30	3143.4	805.62	5511.8
40	2651.5	583.78	4812.7	40	3154.2	810.85	5526.4
50	2661.6	588.04	4827.8	50	3165.1	816.10	5541.0
50 00	2671.8	592.32	4842.9	58 00	3176.0	821.37	5555.6
10	2681.9	596.62	4858.0	10	3186.9	826.66	5570.2
20	2692.1	600.93	4873.1	20	3197.8	831.98	5584.7
30	2702.3	605.27	4888.2	30	3208.8	837.31	5599.3
40	2712.5	609.62	4903.2	40	3219.7	842.67	5613.8
50	2722.7	614.00	4918.3	50	3230.7	848.06	5628.3
51 00	2732.9	618.39	4933.4	59 00	3241.7	853.46	5642.8
10	2743.1	622.81	4948.4	10	3252.7	858.89	5657.3
20	2753.4	627.24	4963.4	20	3263.7	864.34	5671.8
30	2763.7	631.69	4978.4	30	3274.8	869.82	5686.3
40	2773.9	636.16	4993.4	40	3285.8	875.32	5700.8
50	2784.2	640.66	5008.4	50	3296.9	880.84	5715.2
52 00	2794.5	645.17	5023.4	60 00	3308.0	886.38	5729.7
10	2804.9	649.70	5038.4	10	3319.1	891.95	5744.1
20	2815.2	654.25	5053.4	20	3330.3	897.54	5758.5
30	2825.6	658.83	5068.3	30	3341.4	903.15	5772.9
40	2835.9	663.42	5083.3	40	3352.6	908.79	5787.3
50	2846.3	668.03	5098.2	50	3363.8	914.45	5801.7
53 00	2856.7	672.66	5113.1	61 00	3375.0	920.14	5816.0
10	2867.1	677.32	5128.0	10	3386.3	925.85	5830.4
20	2877.5	681.99	5142.9	20	3397.5	931.58	5844.7
30	2888.0	686.68	5157.8	30	3408.8	937.34	5859.1
40	2898.4	691.40	5172.7	40	3420.1	943.12	5873.4
50	2908.9	696.13	5187.6	50	3431.4	948.92	5887.7
54 00	2919.4	700.89	5202.4	62 00	3442.7	954.75	5902.0
10	2929.9	705.66	5217.3	10	3454.1	960.60	5916.3
20	2940.4	710.46	5232.1	20	3465.4	966.48	5930.5
30	2951.0	715.28	5246.9	30	3476.8	972.39	5944.8
40	2961.5	720.11	5261.7	40	3488.2	978.31	5959.0
50	2972.1	724.97	5276.5	50	3499.7	984.27	5973.3
55 00	2982.7	729.85	5291.8	63 00	3511.1	990.24	5987.5
10	2993.3	734.76	5306.1	10	3522.6	996.24	6001.7
20	3003.9	739.68	5320.9	20	3534.1	1002.3	6015.9
30	3014.5	744.62	5335.6	30	3545.6	1008.3	6030.0
40	3025.2	749.59	5350.4	40	3557.2	1014.4	6044.2
50	3035.8	754.57	5365.1	50	3568.7	1020.5	6058.4
56 00	3046.5	759.58	5379.8	64 00	3580.3	1026.6	6072.5
10	3057.2	764.61	5394.5	10	3591.9	1032.8	6086.6
20	3067.9	769.66	5409.2	20	3603.5	1039.0	6100.7
30	3078.7	774.73	5423.9	30	3615.1	1045.2	6114.8
40	3089.4	779.83	5438.6	40	3626.8	1051.4	6128.9
50	3100.2	784.94	5453.3	50	3638.5	1057.7	6143.0

TABLE XLV.—*Elements of a circular curve of 1° curvature, 5,730-foot radius*—Continued

Δ		Tang., T.	Ext. dist., E.	Long chord, L. C.	Δ		Tang., T.	Ext. dist., E.	Long chord, L. C.
°	′				°	′			
65	00	3650.2	1063.9	6157.1	73	00	4239.7	1398.0	6816.3
	10	3661.9	1070.2	6171.1		10	4252.6	1405.7	6829.6
	20	3673.7	1076.6	6185.2		20	4265.6	1413.5	6843.0
	30	3685.4	1082.9	6199.2		30	4278.5	1421.2	6856.4
	40	3697.2	1089.3	6213.2		40	4291.5	1429.0	6869.7
	50	3709.0	1095.7	6227.2		50	4304.6	1436.8	6883.1
66	00	3720.9	1102.2	6241.2	74	00	4317.6	1444.6	6896.4
	10	3732.7	1108.6	6255.2		10	4330.7	1452.5	6909.7
	20	3744.6	1115.1	6269.1		20	4343.8	1460.4	6923.0
	30	3756.5	1121.7	6283.1		30	4356.9	1468.4	6936.2
	40	3768.5	1128.2	6297.0		40	4370.1	1476.4	6949.5
	50	3780.4	1134.8	6310.9		50	4383.3	1484.4	6962.8
67	00	3792.4	1141.4	6324.8	75	00	4396.5	1492.4	6976.0
	10	3804.4	1148.0	6338.7		10	4409.8	1500.5	6989.2
	20	3816.4	1154.7	6352.6		20	4423.1	1508.6	7002.4
	30	3828.4	1161.3	6366.4		30	4436.4	1516.7	7015.6
	40	3840.5	1168.1	6380.3		40	4449.7	1524.9	7028.8
	50	3852.6	1174.8	6394.1		50	4463.1	1533.1	7041.9
68	00	3864.7	1181.6	6408.0	76	00	4476.5	1541.4	7055.0
	10	3876.8	1188.4	6421.8		10	4489.9	1549.7	7068.2
	20	3889.0	1195.2	6435.6		20	4503.4	1558.0	7081.3
	30	3901.2	1202.0	6449.4		30	4516.9	1566.3	7094.4
	40	3913.4	1208.9	6463.1		40	4530.4	1574.7	7107.5
	50	3925.6	1215.8	6476.9		50	4544.0	1583.1	7120.5
69	00	3937.9	1222.7	6490.6	77	00	4557.6	1591.6	7133.6
	10	3950.2	1229.7	6504.4		10	4571.2	1600.1	7146.6
	20	3962.5	1236.7	6518.1		20	4584.8	1608.6	7159.6
	30	3974.8	1243.7	6531.8		30	4598.5	1617.1	7172.6
	40	3987.2	1250.8	6545.5		40	4611.2	1625.7	7185.6
	50	3999.5	1257.0	6559.1		50	4626.0	1634.4	7198.6
70	00	4011.9	1265.0	6572.8	78	00	4639.8	1643.0	7211.6
	10	4024.4	1272.1	6586.4		10	4653.6	1651.7	7224.5
	20	4036.8	1279.3	6600.1		20	4667.4	1660.5	7237.4
	30	4049.3	1286.5	6613.7		30	4681.3	1669.2	7250.4
	40	4061.8	1293.7	6627.3		40	4695.2	1678.1	7263.3
	50	4074.4	1300.9	6640.9		50	4709.2	1686.9	7276.1
71	00	4086.9	1308.2	6654.4	79	00	4723.2	1695.8	7289.0
	10	4099.5	1315.5	6668.0		10	4737.2	1704.7	7301.9
	20	4112.1	1322.9	6681.6		20	4751.2	1713.7	7314.7
	30	4124.8	1330.3	6695.1		30	4765.3	1722.7	7327.5
	40	4137.4	1337.7	6708.6		40	4779.4	1731.7	7340.3
	50	4150.1	1345.1	6722.1		50	4793.6	1740.8	7353.1
72	00	4162.8	1352.6	6735.6	80	00	4808.7	1749.9	7365.9
	10	4175.6	1360.1	6749.1		10	4822.0	1759.0	7378.7
	20	4188.4	1367.6	6762.5		20	4836.2	1768.2	7391.4
	30	4201.2	1375.2	6776.0		30	4850.5	1777.4	7404.1
	40	4214.0	1382.8	6789.4		40	4864.8	1786.7	7416.8
	50	4226.8	1390.4	6802.8		50	4879.2	1796.0	7429.5

TABLE XLV.—*Elements of a circular curve of 1° curvature, 5,730-foot radius*—Continued

Δ		Tang., T.	Ext. dist., E.	Long chord L. C.	Δ		Tang., T.	Ext. dist., E.	Long chord, L. C.
°	′				°	′			
81	00	4893.6	1805.3	7442.2	86	00	5343.0	2104.7	7815.2
	10	4908.0	1814.7	7454.9		10	5358.6	2115.3	7827.4
	20	4922.5	1824.1	7467.5		20	5374.2	2126.0	7839.6
	30	4937.0	1833.6	7480.2		30	5389.9	2136.7	7851.7
	40	4951.5	1843.1	7492.8		40	5405.6	2147.5	7863.8
	50	4966.1	1852.6	7505.4		50	5421.4	2158.4	7876.0
82	00	4980.7	1862.2	7518.0	87	00	5437.2	2169.2	7888.1
	10	4995.4	1871.8	7530.5		10	5453.1	2180.2	7900.1
	20	5010.0	1881.5	7543.1		20	5469.0	2191.1	7912.2
	30	5024.8	1891.2	7555.6		30	5484.9	2202.2	7924.3
	40	5039.5	1900.9	7568.2		40	5500.9	2213.2	7936.3
	50	5054.3	1910.7	7580.7		50	5517.0	2224.3	7948.3
83	00	5069.2	1920.5	7593.2	88	00	5533.1	2235.5	7960.3
	10	5084.0	1930.4	7605.6		10	5549.2	2246.7	7972.3
	20	5099.0	1940.3	7618.1		20	5565.4	2258.0	7984.2
	30	5113.9	1950.3	7630.5		30	5581.6	2269.3	7996.2
	40	5128.9	1960.2	7643.0		40	5597.8	2280.6	8008.1
	50	5143.9	1970.3	7655.4		50	5614.2	2292.0	8020.0
84	00	5159.0	1980.4	7667.8	89	00	5630.5	2303.5	8031.9
	10	5174.1	1990.5	7680.1		10	5646.9	2315.0	8043.8
	20	5189.3	2000.6	7692.5		20	5663.4	2326.6	8055.7
	30	5204.4	2010.8	7704.9		30	5679.9	2338.2	8067.5
	40	5219.7	2021.1	7717.2		40	5696.4	2349.8	8079.3
	50	5234.9	2031.4	7729.5		50	5713.0	2361.5	8091.2
85	00	5250.3	2041.7	7741.8	90	00	5729.7	2373.3	8103.0
	10	5265.6	2052.1	7754.1		10	5746.3	2385.1	8114.7
	20	5281.0	2062.5	7766.3		20	5763.1	2397.0	8126.5
	30	5296.4	2073.0	7778.6		30	5779.9	2408.9	8138.2
	40	5311.9	2083.5	7790.8		40	5796.7	2420.9	8150.0
	50	5327.4	2094.1	7803.0		50	5813.6	2432.9	8161.7

NOTE.—If $\Delta \times D$ is less than 600, the error in **tang. dist.** of the above table is less than 0.4 ft. If $\Delta \times D$ is less than 400, the error in tang. dist. is less than 0.25 ft. If $\Delta \times D$ is less than 200, the error in tang. dist. is less than 0.1 ft.

158. Preliminary survey.—*a. General.*—After the reconnaissance of the routes that appear most favorable and the determination of the general route to be followed, a preliminary survey is begun. The officer who made the reconnaissance should be in charge of the survey.

b. Organization.—The survey party is organized into three groups: A *transit party* consisting of one instrumentman, two chainmen, two flagmen, and a number of axemen; a *level party* consisting of one levelman and one or two rodmen; and a *topographical party* consisting of one topographer and two chainmen.

c. Procedure.—The locating engineer's place is at the head of the transit party. The head chainman works under his direct supervision. The locating engineer selects the points where it is necessary to change the course and these points are marked by driving hubs (not less than 2 inches in diameter) in the ground. A tack is placed in each hub to indicate the center line.

d. Stationing.—The chainmen measure the distance along the center with 100-foot chain, setting stakes every 100 feet which are known as stations. The stations are numbered serially beginning with No. 1. The numbers are marked on the face of the stakes with crayon.

e. Hubs.—The head flagman is directed by signals from the transit man as to the center line of the survey. He locates the point where the hubs are to be placed and the points where the tacks are to be driven in the hubs. The rear flagman holds a flagpole on the tack in the first hub directly back of the transit man and which is known as the back or rear sight.

f. Clearing.—The axemen clear away the brush and obstructions and work under the direction of the head chainman. One axeman should be detailed to make stakes for the transit party.

g. Notes.—The method of recording the transit notes is illustrated in Table XLVI.

h. Levels.—The level party establishes bench marks and takes levels along the traverse, taking a reading and recording the elevation at each 100-foot station. The elevation of the starting point, if not definitely known, may be assumed to be 100, 1,000, etc., feet above datum. Two or more bench marks should be established in every mile. The method of recording the level notes is illustrated in Table XLVII. These notes are used to assist in preparing a contoured map and the bench marks are used as checks in making the field location.

i. Topography.—The topographic party records topographic data on each side of the center line by stadia readings, obtaining the data necessary to draw in contour lines and locate features of the landscape over a territory extending at least 500 feet on each side of the center line.

159. Paper location.—Upon the map and profile prepared from the notes taken in the preliminary survey, a "paper location" of the proposed railway line is projected (see figs. 88 and 89). The line of the preliminary survey is shown in Figure 88 as a broken line, and the line being located is shown as a solid line. The grade elevation for each station on the line being located is taken from the profile (fig. 89) or it is obtained by interpolation between the contours in Figure 88; points having the required elevation are located opposite the corresponding stations of the preliminary survey. These points are inclosed in a circle and marked with the number of the station of the preliminary survey to which they correspond. A line joining the points thus marked is called the grade contour.

TABLE XLVI.—*Preliminary survey (transit notes)*

Coal River extension. Transit Notes, page 6	Preliminary survey, 7-16-26. Cloudy 75°	Party: Doe, Inst.; Roe; Jones; Smith

Stations	Deflection	Course	Remarks
46+00—P.O.T.			
		N. 26° 30′ E.	
39+40 ⊙	5° 30′ L.	N. 32° 00′ E.	12′ Oak 15′ N. 15′ Sycamore 30′ S.
38+00 ⊙	26° 00′ L.	N. 58° 00′ E.	40′ South Jake. Pettry d'w'g. S. E. Cor.
36+60 ⊙	22° 30′ L.	N. 80° 30′ E.	Opp. pt. of hill 50′ below falls at Pettry's ford.
30+00 P.O.T. BS.			

TABLE XLVII.—*Preliminary survey (level notes)*

Coal River extension. Level notes, page 10	Preliminary survey, 7-16-26. Cloudy 75°	Party: Jackson, Inst.; Peters.

Sta.	Rod R'd'g	H. I.	EL	Remarks
BM	5.50	130.50	125.00	Nail in Sycamore root. Sta. 29+90 6′ N. 6″ beech 10′ E.
30+00	4.3		126.2	
1	6.4		124.1	
2	6.9		123.6	
3	7.5		123.0	
4	5.7		124.8	
T.P.	−F.S.=2.20			
	+B.S.=8.60	136.90		
35+00	11.8		125.1	
6	10.9		126.0	
7	1.7		135.2	
T.P.	−F.S.=2.10			
	+B.S.=14.60	149.40		
38+00	11.4		138.0	
9	9.9		139.5	
40+00	11.4		138.0	
1	8.9		140.5	
BM	6.62		142.78	Spike in River boulder 41+12 12′ L.$ under 3 cedar trees 12′ high.

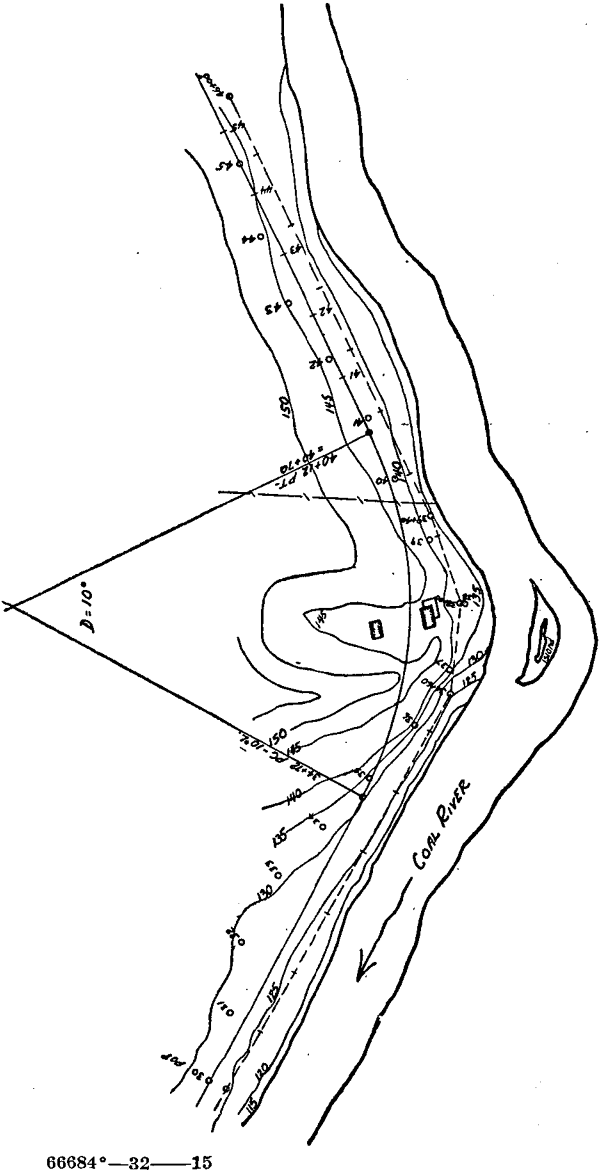


FIGURE 88.—Map prepared from preliminary survey, showing paper location

The paper location is made by selecting a line that will as nearly as possible conform to the configuration of the ground, so as to avoid as much as possible the making of heavy cuts and fills. An approximate profile of the ground along the paper location is then made and approximate grades established, paying particular attention to endeavor to balance cuts and fills within certain sections as much as possible.

This paper location is then taken into the field and used by the final locating parties.

160. Field location.—One or more field parties may be organized in accordance with the urgency of the situation. If only one party is organized, it first establishes the first tangent in the field by scaling from the paper location the distances from the original traverse to this tangent at convenient points and

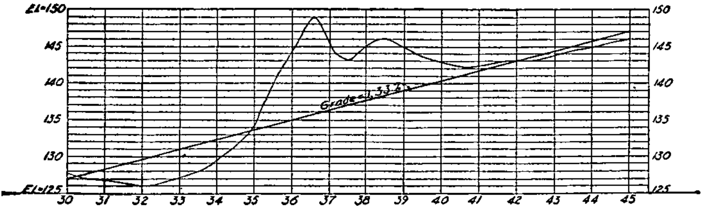


FIGURE 89.—Preliminary profile and paper location

establishing base points in the field. It then establishes the second tangent in the same manner, produces these two tangents to a common point of intersection and measures the central angle. With this point of intersection and the degree of curvature shown on the paper location, the party then establishes the tangent distance, which is measured back from the point of intersection to the point of curve and ahead from the point of intersection to the point of tangent. The stationing is established on the tangent up to this curve, and the correct station of the point of curve is then determined, the instrument set up on this point of curve and the curve laid out as described in paragraph 157. The party then proceeds with the stationing on the second tangent until it reaches approximately the point of curve of the next curve. The third tangent is then established in the same manner as described above, the point of intersection fixed, the degree of central angle measured, and the curve laid out again in the same manner as described for the first curve. The notes kept by this party are illustrated in Table XLVIII. If two or more parties are sent out in the field to establish the line, the line is divided into several sections according to the number of parties and each party begins with the establishing of the first tangent within its section and proceeds as described above, with this difference, that it does not establish the stationing on the line but merely determines by stakes the points of curve and points of tangent, so that the party following can proceed without interruption. In other words, the second, third, or fourth parties will only lay out the line, chopping down trees and clearing brush where necessary so as to have a clear sight for establishing the tangents and points of curve. The chaining is carried on by party No. 1, who will then upon arriving at the section of party No. 2 or 3 lay out the curves as found necessary. Where two parties join and where revisions have been necessary in the paper location, a modification will have to be made in the curve joining the tangents of the two adjacent sections, but the degree of curvature on the paper location should be adhered to if possible. After the location has been definitely established in the field and stakes placed every 100 feet on the line, a leveling party is organized which will take levels at every one of these stakes, establishing bench marks as they go along. This leveling party should follow immediately after party No. 1 as described elsewhere so as not to delay this work. The level notes kept by this party are similar to Table XLVII.

TABLE XLVIII.—*Final location (transit notes)*

Coal River extension Transit notes page 8	Location. 7-30-16. Clear 90°	Party {Doe, Inst. Roe Jones, Smith

Sta.	Def.	Chk. Def.	Course	Remarks
45+00⊙P. O. T.			N. 27° 10′ E.	
PT. 40+12⊙=40+70 ahead	27° 00′	54° 00′		
40	26° 24′			{D=10° A=54° 00′
39	21° 24′			T=291.94′
38	16° 24′			L=540′
37	11° 24′			
36	6° 24′			
35	1° 24′			
PC. 34+72⊙10° L.				
BS. P. O. T. 30+00			N. 81° 10′ E.	

161. Construction stakes.—In order to proceed with the grading, grading stakes are set out which are placed at the top of a slope when in a cut, and at the foot of a slope when on a fill. The construction party grades up to or down from these stakes. No further instrumental work is necessary except for the definite location of culverts, abutments or structures of this kind. It is advisable to place stakes at 50-foot intervals on sharp curves. For curves having a degree up to 6°, it is not necessary to place stakes closer than 100 feet apart for military railroads.

162. Preparation of the subgrade.—*a. Methods.*—In the preparation of the subgrade, use may be made of any or all of the following: Steam shovels, wheel scrapers, drag scrapers, wheelbarrows. The scrapers may be drawn by animals or tractors, and in certain situations excavation may be done by hand labor with pick and shovel. Steam shovels are used when the work consists of heavy cuts and fills, and the material from cut is to be hauled a considerable distance. The material may be moved in dump cars on narrow gauge track, or by wagons or trucks. Wheel scrapers are used when the work consists of cuts and fills and the quantity in cuts is approximately equal to the quantity in adjacent fills, or when material can be conveniently wasted within a reasonable distance of the cut. Wheel scrapers are used when the fill is greater than 4 feet. When fill is less than 4 feet, drag scrapers may be used. Wheelbarrows are used when the work consists of side borrows or in low marshy ground and where the fills are less than about 4 feet in depth.

b. Grading for new construction.—New construction of the roadbed for standard gauge lines is best carried out by the use of tractor-tread steam or gasoline shovels using light standard gauge air-operated side dump cars of 16 or 20 yards capacity and light standard gauge steam donkey engines to move the earth from cut to fill. Ties and rail for a light construction track are brought up by wagons or trucks. Where the roadbed is to lie on a side hill slope, a pioneer grade just wide enough for the construction track should be made by working the shovel and casting the material for the length of the entire side hill section. The shovel is then brought back to the initial point and the work of widening the grade is started. As a section of construction track is laid on the pioneer grade the dump cars are shoved up to the shovel, the cars are loaded and moved to a point where material is needed. Where through cut sections are necessary, start the shovel at grade at the point where the cut begins. Where fills are necessary, very light trestles are constructed from which the cars are dumped. The work can be carried out with narrow gauge equipment with equal facility, but even in this case time is saved in the final construction if full-sized ties for the standard gauge track are used for the narrow gauge construction track.

c. Grading of captured lines.—Grading of captured lines consists of repairing the roadbed in spots where breaks have been caused by enemy demolitions. Earth is obtained from nearest sources, either by widening cuts or by taking it from side borrows.

163. Tracklaying.—*a. General.*—Laying the track upon the finished subgrade may be accomplished in several ways. One method is by extending the track with materials supplied over the line by a work train which advances as the track is laid. Where good highways exist, motor trucks can be employed to distribute track material, except ballast, in dumps at intervals of from one-half to one mile apart along the line. Tracklaying can then start from several points simultaneously, materials being distributed by teams or trucks along the grade. Care must be taken in this case to fill all ruts made in the subgrade by the vehicles before the track is laid. Where the track is to be laid parallel to an existing track, the problem is simplified by the possibility of dumping ballast upon the prepared subgrade from the existing tracks. The new track can then be laid directly upon the ballast.

b. Organization.—Where the subgrade has been completely prepared, ties, rail, and accessories, and ballast are brought to the end of the existing rail on cars pushed ahead of a locomotive. On the first three flat cars are stacked about 1,500 ties. These cars are followed by two flat cars loaded with about 150 rails, followed by a flat car loaded with splice material, tie plates, and spikes, followed by a flat car carrying all necessary tools for the working parties. The above quantities of materials are sufficient to lay about one-half mile of single track. Ballast is brought up in a separate train. The organization and duties of the tracklaying party may be as follows:

TABLE XLIX.—*Typical organization for tracklaying party for laying track with work-train service*

Duties	Superintendent	Foreman	Subforeman	Squad leader	Workers	Teams or trucks
General supervision	1	----	----	----	----	----
Unloading ties	----	----	----	1	7	----
Carrying and placing ties	----	----	----	2	14	----
Unloading and hauling rails	----	----	1	1	7	1
Handling and placing splice bars, tie plates, spikes, bolts, etc., ready for use	----	1	----	2	14	----
Laying rail, temporarily bolting splice bars, spiking about every other tie ahead of work train	----	----	1	4	28	----
Full bolting and spiking behind work train	----	----	1	2	14	----
Unloading ballast from ballast train	----	----	----	2	14	----
Bringing rails to a proper surface and alignment. Tamping ties	----	1	1	6	42	----
Checking up and correcting any errors in grade, surface, alignment, spiking, bolting, etc	----	----	----	1	7	----
Total	1	2	4	21	147	1

c. Alignment.—The alignment of the track is defined by stakes set on the center line of the proposed track at intervals of 100 feet. The exact center is marked by tacks in the head of the stakes. The center stakes should be left at least 1 foot above the surface of the finished subgrade in order that they may be referred to even after the track has been raised on ballast. One side of the track is referred to as the line side. As crossties vary several inches in length, a tolerance of 3 inches being allowed in common practice, it is customary to make the ends of the ties line up on one side of the track. Thus, on a track running generally east and west the south rail may be designated as the line rail. The opposite rail, laid at gauge distance from the line rail, is called the gauge rail. On curves the line side is always the inside of the curve regardless of direction. On double track lines the outside rail on each track is the line side, whether on tangent or curve. The ties are installed so that their line side will be a fixed distance from the web of the line rail. This distance is such as equally to space the rail bearing on standard ties. It is generally 22½ inches from the web of the rail to the end of the tie. The spikers are instructed to cut a notch in the handle of their spike mauls 22½ inches from the end, and a tie should be

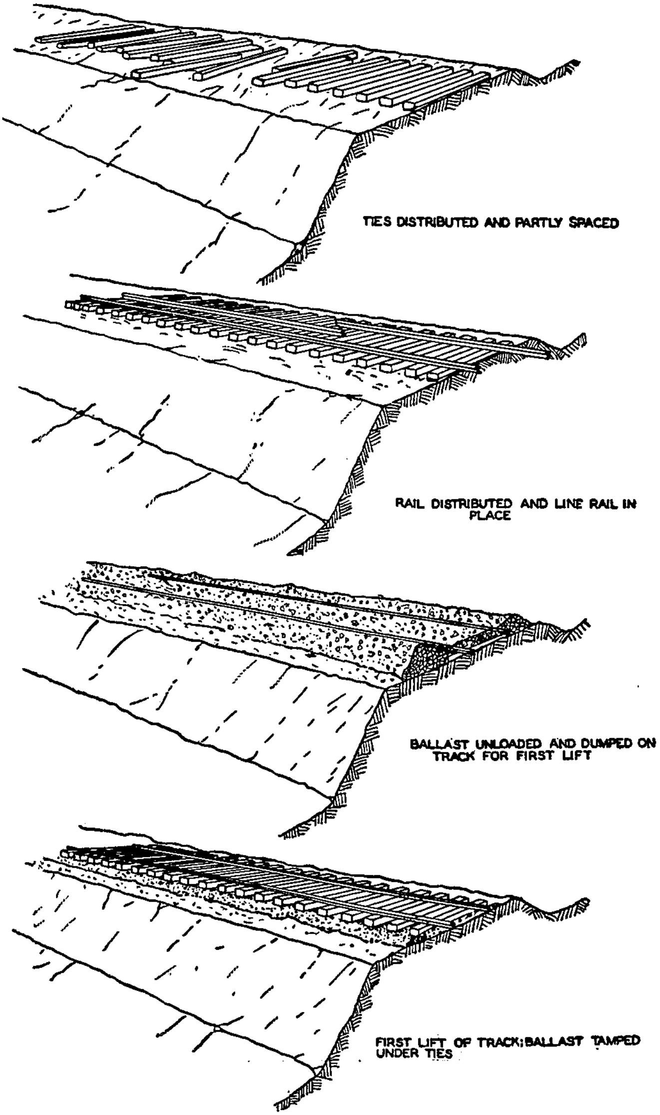


FIGURE 90.—Steps in laying and ballasting tracks

shifted under the rail before spiking so that the end comes even with this notch when the end of the maul handle is placed against the web of the rail.

d. Tie plates.—Special bearing plates called tie plates, about 6 inches wide and long enough to provide a safe bearing area for the rail on the face of the tie and protect the latter from the cutting action of the rail, and with a shoulder to restrain the outward movement of the rail are desirable on all track, both tangent and curve, but when insufficient tie plates are available preference should be given to the sharpest curves. The shoulder of the tie plate is placed on the outside of the rail, fitting the outside base of the rail snugly.

e. Joints.—On curves and on tangents of less than 500 feet in length, the rail is laid with broken joints; that is, a joint on the gauge rail is located about opposite the middle of a length of line rail. Short rails are introduced as necessary on the inside of long curves to produce this result. On tangents of a greater length than 500 feet, the joints should be square; that is, the joints in each rail should be directly opposite each other, since this aids in maintaining the cross level of the track. Before the rail is spiked to the ties at the joints, all bolts in the joints should be fully tightened in order to prevent kinking of the rail. Lock washers should be used on each bolt.

f. Allowance for expansion.—Metal shims should be used between the ends of the rails to provide a space to permit temperature expansion of the rail. The thickness of the shim to use varies with the temperature of the rail at the time of laying, as shown by a thermometer placed on the rail, in accordance with the following table.

TABLE L.—*Temperature expansion for laying rails*

[Based on 33-foot rail lengths]

Temperature (Fahrenheit)	Allowance
0° to 25°	¼ inch.
25° to 50°	3/16 inch.
50° to 75°	⅛ inch.
75° to 100°	1/16 inch.

For light railways using 16½-foot rail lengths, divide the above allowance by 2.

Where metal shims are used they are removed as soon as the bolts in the joint have been tightened.

g. Spiking.—In spiking the rail to the ties, the outside spike should be set ahead of the inside spike to prevent the slewing of the tie (see fig. 91). The line side rail is spiked first. In spiking the opposite or gauge rail the track gauge is used at every fourth tie. The intermediate spikes can then be driven without using the gauge.

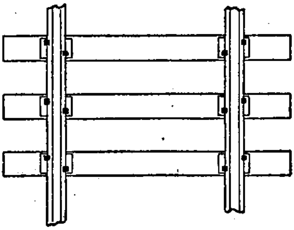


FIGURE 91.—Method of setting spikes

h. Ballasting.—Ballasting is done in two operations or raises. The ballast material is dumped on top of the track which is then raised by jacks to a little below the desired grade. The ballast is then tamped under the ties for, e. g., one foot in both directions from each rail. After the track has been allowed to settle for a few days under work-train traffic, a second dumping of ballast is made, the track is raised and jacked up to the desired grade and the ties are again tamped for a distance of one foot on each side of each rail. Jacks should not be applied directly under the joints, as this is likely to break the splice bars.

TABLE LI.—*Standard gauge railway—Cubic yards of ballast per mile of track*

[Ties 6 by 8 inches by 8 feet, spaced 20 inches center to center; ballast dressed even with the tops of the ties and sloping from the ends of the ties 1 on 4]

Inches of ballast under tie	Cubic yards of ballast per mile
4	1,529
5	1,779
6	2,032
7	2,295
8	2,577
9	2,863
10	3,137

TABLE LII.—*Standard gauge railway—Materials for 1 mile of single track*

Weight per yard (lb.)	Rail gross tons	90%—33'; 10%—28'			Spikes (4 per tie)						
		Splice bars (pairs)	Bolts		Size	Ties spaced 18" c. to c., 22 per 33' rail, 3,520 per mile		Ties spaced 20" c. to c., 20 per 33' rail, 3,167 per mile		Ties spaced 22" c. to c., 18 per 33' rail, 2,880 per mile	
			Average size	Approx. kegs (4 per joint)		Pcs.	Kegs	Pcs.	Kegs	Pcs.	Kegs
50	78.57	325	¾ x 3	4.6	9/16 x 5½	14,080	42.66	12,672	38.38	11,520	34.91
55	86.43	325	¾ x 3¼	4.7	9/16 x 5½	14,080	42.66	12,672	38,38	11,520	34.91
60	94.29	325	¾ x 3½	4.9	9/16 x 5½	14,080	42.66	12,672	38,38	11,520	34.91
70	110.00	325	¾ x 4	5.2	9/16 x 5½	14,080	42.66	12,672	38.38	11,520	34.91
75	117.86	325	⅞ x 4	7.7	9/16 x 5½	14,080	42.66	12,672	38,38	11,520	34.91
80	125.71	325	⅞ x 4¼	7.9	9/16 x 5½	14,080	42.66	12,672	38.38	11,520	34.91
85	133.57	325	⅞ x 4½	8.2	9/16 x 5½	14,080	42.66	12,672	38.38	11,520	34.91
90	141.43	325	1 x 4½	10.8	9/16 x 5½	14,080	42.66	12,672	38.38	11,520	34.91
100	157.14	325	1 x 4¾	11.2	9/16 x 5½	14,080	42.66	12,672	38.38	11,520	34.91
105	165.45	325	1 x 4¾	11.2	9/16 x 5½	14,080	42.66	12,672	38.38	11,520	34.91
				(6 per joint)							
110	172.86	325	1 x 5	17.4	⅝ x 6	14,080	55.21	12,672	49.68	11,520	45.17
120	188.57	325	1 1/16 x 5	19.7	⅝ x 6	14,080	55.21	12,672	49.68	11,520	45.17
130	204.29	325	1⅛ x 5½	21.9	⅝ x 6	14,080	55.21	12,672	49.68	11,520	45.17
140	220.00	325	1 3/16 x 5½	23.2	⅝ x 6	14,080	55.21	12,672	49.68	11,520	45.17

i. Lining.—In lining track to the center stakes, 8 or 10 men with lining bars, working under the direction of a foreman, are usually sufficient. The foreman measures the distance that the track will have to be thrown at a center stake. The men place their lining bars under the rail and by heaving together move the track to the proper location. Another center stake, preferably 200 or 300 feet distant, is then selected and same operation repeated. The foreman then lines the track by eye between these two points. The use of more than 10 or 12 men with lining bars is usually disadvantageous on account of a tendency to throw the track too far at one time.

j. Surfacing.—Surfacing is the act of giving the track evenness or smoothness over short distances. In surfacing the track, jacks are worked in pairs opposite each other. It is necessary to dig jack holes in the ballast to allow the foot of the jack to go under the rail at intervals of from 10 to 20 feet. The jacks should always be set on the outside of the rail, because it is easier to remove jacks so set, and men working on opposite jacks do not interfere with each other. The foreman in charge of surfacing raises one rail to the proper elevation by eye and brings the opposite rail up to the proper elevation by use of the track level; the ties are then well tamped.

k. Dressing.—Completely ballasted track should be dressed so that the ballast is even with the tops of the ties from end to end,

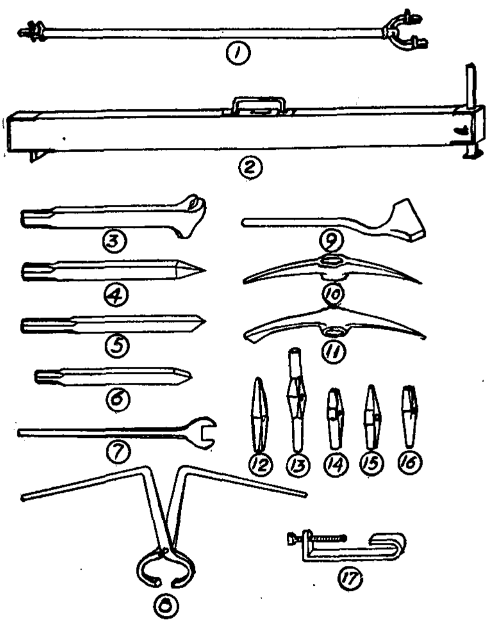


Figure 92.—Track tools

① Track gauge	⑩ Pickaxe (clay pick)
② Track level	⑪ Tamping pick
③ Claw bar	⑫ Spike maul
④ Lining bar	⑬ Spike maul (Pittsburgh pattern)
⑤ Crowbar (pinch point)	⑭ Track chisel
⑥ Crowbar (wedge point)	⑮ Track punch
⑦ Track wrench	⑯ Track punch (round point)
⑧ Rail tongs	⑰ Rail clamp
⑨ Tamping bar	

then to a slope of 1 on 4 to the subgrade. With the poorer qualities of ballast that do not drain well, it is essential that the lower surface of the ends of the ties be kept above the surface of the ballast, or churning will take place. Where such ballast is used, slope the ballast between the ties from the rail to the lower edge of the tie. When rock ballast is not used, track is surfaced with dirt in a similar manner, adding a rounded crown between the rails to insure drainage.

164. Curving rails.—The curving of rail with a rail bender is necessary only in track of very sharp curvature, not likely to be found on standard-gauge military railways. For the curves used on military railways, the rails are sufficiently flexible so that the curving can be easily accomplished by spiking the rail to the ties, and lining to the curve, as described.

165. Cutting rail.—The best method for cutting heavy rail sections in the field is as follows: Mark the rail with a track chisel around its entire circumference at the point where it is desired to break it. Set the rail upright on the ties in a track with one end in contact with a running rail. Set two spikes firmly in a tie, fastening the piece of rail at the point marked. Eight or ten men using lining bars then line the free end of the rail away from the running rail, creating as great a strain at the point marked as possible. A blow with a hammer on the head of the rail at the marked section will then cause it to break. To cut a piece of rail of 3 feet or less, it is necessary to mark the entire circumference of the rail very deeply with a track chisel. Generally, after the entire circumference has been marked to a depth of from one fourth to three eighths of an inch, a few blows of a hammer will cause the piece to drop off. Rail can also be cut with the oxyacetylene torch or with a hack saw.

166. Superelevation of outer rail.—*a.* When a train runs on a curve there are two forces acting to crowd the wheel flanges against the outer rail—centrifugal force and the tendency of the stiff trucks to run straight. The former varies as the square of the speed; the latter is constant for all speeds. If the train is stretched, that is, a tension on all drawbars, the pull of the locomotive works against these two forces and tends to draw the trucks to the inner rail, but this effect is small, variable, and negligible.

b. To reduce pressure on the outer rail on curves, it is elevated above the inner rail by a certain amount. A safe rule for standard gauge is to elevate three-fourths inch per degree of curvature, attaining this elevation gradually on the tangent and reaching full elevation at the point of curve. This rule is modified or not applied on curves in special situations where all traffic must run at low speed, as at important stations, crossings, in yards, etc.

It is not used on switches and yard tracks, which are adapted to low speed only.

167. The practical installation of a turnout.—*a.* Many types of switch material are in use on commercial railways, each railway having its own standards, but the essential items for installing a turnout are as follows, the weight and section of rail corresponding to that in the track:

(1) One set switch ties, according to the frog number. A turnout may be installed without switch ties by interlacing track ties.

(2) One switch, complete, consisting of 2 switch points, right and left, with lugs; and rods, plates and braces, approximately as follows depending on the type: 2 rods, 14 plates and braces. In some types of material the rods are adjustable.

(3) One frog. If a spring frog, right or left hand must be specified, depending on whether turnout is to the right or left.

(4) Two guard rails. Guard rail clamps, one for each guard rail, are desirable but not essential. The guard rail may be bolted to the track rail, but will serve without clamps or bolts if properly spiked and braced.

(5) One switch stand.

(6) One connecting rod, adjustable, from switch stand to head rod.

(7) Necessary rail, angle bars, and track fastenings, depending on the length of the lead.

(8) Foot guards are desirable but not essential for the heel, toe, and wing rails of frogs, ends of guard rails, and heels of switch points. They may be of wood or metal and may be improvised.

b. Assuming that the main line is in existence and it is desired to install a turnout, it is first necessary to determine the desired location of point of frog and the number of frog to be used. Table LIII gives the data for turnouts with the frog numbers in most common use. In cases in which the frogs available are not of any of the numbers given, the same data can be determined by measuring an existing turnout which has a frog of the same number as the one to be used. In general, on commercial railways in the United States, No. 7 or No. 8 frogs are used in yard tracks, No. 10 frogs in main-line turnouts, and No. 16 or No. 20 frogs at the ends of double track. For the purpose of simplifying the problem of supply, it has been decided that engineer depots will be prepared to furnish only No. 8 frogs. These are suitable

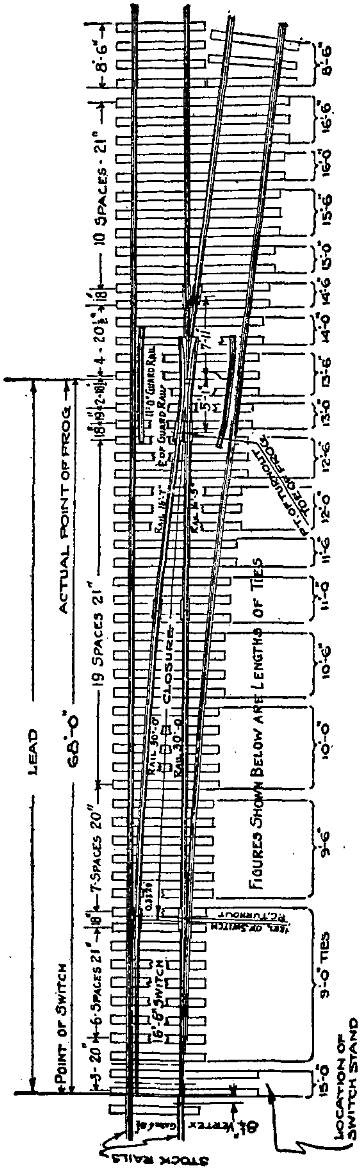


FIGURE 93.—Typical layout of No. 8 turnout standard gauge railway

for general use. Problems which may be encountered in yard revision or in locating new switches in complicated existing track layouts may be solved on paper by plotting the existing tracks on a scale of one-eighth inch equals 1 foot, or greater, and then testing various plans. It is sometimes necessary to vary from standard switch leads, but the curvature must not exceed 16°.

c. It is approximately true that when a switch is on the inside of a curve the degree of a curve of the switch is its normal degree plus the degree of curve of the main line. Thus, if a No. 8 frog calling for a curve of 11¾° were installed on the inside of a 8¼° curve, the result would be that the curvature through the turnout would be 11¾+8¼=20°. On account of the danger of derailment due to trains using a switch at too great a speed and also due to excessive maintenance, it should be remembered that switches should not be located so that the degree of curvature of the turnout curve will be in excess of 16°.

d. After the location and number of the frog have been determined, a stake in the center of the track or mark on the rail should be placed to locate the point of switch. The lead distance is measured from this point to determine the location of the switch point.

e. Measurements should be taken to determine the number and length of the rails to be cut. Joints must not fall in the continuous rails between the point and heel of the switch points or between the ends of the guard rails. Rail cuts should be made before commencing to install the switch.

f. Pull all spikes from every other crosstie throughout the length to be occupied by switch ties and remove the ballast from around these unspiked crossties. Set track jacks under the rail and loosen the track by jacking it up very slightly. Withdraw the loose ties and substitute switch ties of the proper length. Then remove the remainder of the crossties and substitute switch ties in a similar manner. The next operation is to set the frog. This can be done in 15 minutes by a party of 12 experienced men and consists merely of taking out the rail where the frog is to be located, setting the frog into place, spiking it up to gauge and making the connection with the proper length of cut rail and ininstalling a guard rail opposite the frog. Assemble the inside lead rail, join it to the frog and the switch point and spike it up so as to allow 6¼ inches clearance between the heads of the rail at the heel of the switch, leaving the rail to be shifted back and forth between the heel of the switch and the frog. Line the lead rail by eye and spike it. Unspike and line out the main line rail on the turnout side. Fit the slide plates beneath it and place the switch point against it. When the main line rail (stock rail) is lined to the proper point, the gauge will just fit from the opposite main line rail to the gauge line of the switch point. Both the switch point and the stock rail should be spiked at this time and a rail bender should be applied so as to produce a slight kink in the stock rail 8¼ inches ahead of the switch point so that the switch point may fit against the stock rail without creating a line kink. Lay the outside lead rail connecting with the stock rail at gauge distance from the inside lead rail. Install the guard rail opposite the frog on the outside lead rail. It is important that the gauge fit exactly from the point of frog to the outside lead rail and that the guard rail provide a flangeway of 1¾ inches.

g. The main line side switch point may now be installed, the head and back rods applied, switch stand set up on the turnout side of the main line and the connecting rod installed. It will always be necessary to adjust the head and back rods in such a manner that each switch point will fit snugly when thrown against the stock rails.

h. An experienced foreman and 12 men can install a turnout in two working days of eight hours each, provided material is assembled and ready for installation. Where a new switch is installed incident to the construction of the main line itself, a turnout can be completely installed and ballasted in eight hours.

TABLE LIII.—*Typical turnouts for standard gauge railway*

	Frog No.		
	7	8	10
Frog angle	8° 10′	7° 09′ 10″	5° 43′ 29″
Frog length	12′ 2″	13′ 0″	16′ 6″
Switch length	15′ 0°	16′ 6″	16′ 6″
Switch angle	1° 40′	1° 44′ 11″	1° 44′ 11″
Lead	64′ 6″	68′ 0″	78′ 9″
Straight closure	45′ 0″	46′ 5″	55′ 10″
Curved closure	45′ 2 15/16″	46′ 7″	56′ 0″
Point of switch to heel of frog	72′ 2″	75′ 11″	88′ 10″
Point of switch to end of switch ties	90′±	93′ 0″	114′ 6″
Point of switch to 12′ clearance point	121′±	127′ 3″	151′ 1″±
Point of switch to point of switch on ladder tracks 13 feet center to center	91′ 6⅛″	104′ 5¼″	130′ 4″
Point of switch to point of switch, required minimum	77′±	81′±	94′±

NOTE.—The meaning of the terms used in this table will be clear from an examination of Figure 93.

168. Ladder tracks.—Ladder tracks are used to connect the main line with the several tracks of a yard successively. (See fig. 94.) Where the yard tracks are to run parallel to the main line, the main line turnout of the ladder track and the yard track turnouts from the ladder track should be laid with frogs of the same frog number. No. 7 or No. 8 turnouts are generally used on ladders. The distance, center to center, of yard tracks is governed by the purpose for which the yard is designed. In classification yards, 13 feet from center to center is suitable. Elsewhere, for convenience in loading and unloading from motor vehicles and wagons, there should be a lane of adequate width for vehicle operation between each pair of yard tracks.

169. Rehabilitation of captured railways.—*a. Reconnaissance.*—The reconnaissance is of especial importance because the information thus obtained becomes the basis upon which are determined the kind and quantity of materials to be procured and the priority of work. The reconnaissance should preferably be made by the commander of the troops who will be charged with the reconstruction. Especial attention should be paid to the discovery of stocks of track materials and sources of ballast which could be used.

b. Probable character of damage.—Deliberate demolition of the line to a greater or less extent must be anticipated. Bridges will be found destroyed, tunnels blocked, track removed or damaged by explosives, ties removed and possibly burned, stations and watering and fueling facilities demolished. Contact or delayed action mines may have been placed in the roadbed or bridge abutments and piers. In addition to deliberate demolitions by the enemy it may be expected that the roadbed will be found damaged by shell fire, weakened by the construction of

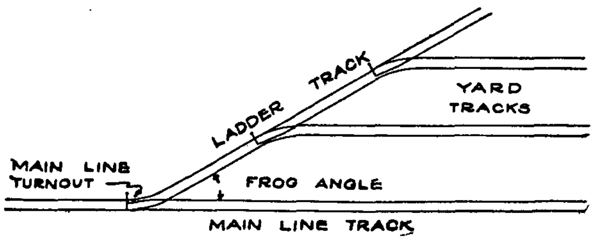


FIGURE 94.—Ladder track

cave shelters in embankments, and deteriorated as a result of neglect and the forces of nature.

c. Priority of work.—The first consideration is to restore single-track operation. This includes the provision of passing tracks and locomotive watering facilities. In the case of a double track line advantage is taken of those portions of either existing track which can be most easily repaired, connecting the useful parts of both tracks by short sections of track in order to get a serviceable single track as soon as possible. Poor conditions of surface, line and drainage are corrected after single-track operation has been established.

d. Execution of work.—Time is saved by sending working parties forward by motor transport or marching in advance of the construction railhead to make repairs to the roadbed and clear it of damaged rail, ties, and other débris. This facilitates the work of the track-laying party which is pushed forward with the work train. Materials may be salvaged from spurs and sidings to make repairs to the main line. Where bridges have been destroyed or tunnels effectively blocked, diversion or shoo-fly tracks may be constructed to circumvent the obstruction temporarily, but before undertaking such step the engineer should first carefully compare the labor and time of constructing the shoo-fly with that required to correct the difficulty on the existing line. Quarries and gravel pits are opened up at convenient points along the line for procurement of ballast. In order to expedite the work a standard of alignment, surface or track materials may be acceptable which is only strict enough to permit of low-speed operation, but careful attention must be given to essential requirements, such as clearances, maximum curvature, maximum grade, and the prevention of soft spots in the roadbed.

Section IV

OPERATION

170. General.—Trains are operated under the divisional system, the railway division being the smallest self-contained unit of a railway capable of operation, maintenance of way, and maintenance of equipment. Railways operated by military personnel are generally operated by engineer railway battalions organized in accordance with the principles described in Engineer Field Manual, Volume I, for engineer railway battalions. If troops other than engineer railway battalions are employed in the operation of military railways they should be organized similarly.

171. Rules.—Military railways are operated in accordance with the standard code of the American Railway Association, modified, if necessary, to meet the peculiar conditions on the military railway.

Section V

MAINTENANCE OF WAY

172. Section work.—A section comprises from 5 to 7 miles of single track, and where practicable the middle of the section lies at a station. The section foreman sees that the rail joints are kept up, that the crossings are in repair, that the track is kept in alignment, that bad ties are replaced with good ones, and that a thorough inspection is made of his section as often as the conditions necessitate, and always once a day. He keeps sharp lookout for broken rails, fires on wooden structures, and washouts. During rainstorms he patrols his section and immediately reports any danger that may threaten, and stops all traffic if necessary or places slow orders until proper repairs have been made. He inspects for and reports any break in the telegraph lines.

173. Track maintenance.—Constant attention is necessary to keep track in good condition. The principal points to be attended to are to keep all ditches and drains clear, and to deepen them rather than to allow them to grow shallow; to keep spikes and bolts tight, rails in line and grade, and the ties solidly tamped, and to remove worn-out or broken rails and ties. For a military road the repair of the enemy's depredations will furnish a large percentage of maintenance work.

174. Tamping.—Tamping in maintenance is a slightly different operation from tamping new track, and other tools are used. The space to be tamped is that between the tie and a trough in the well-packed ballast. A tamping bar (fig. 92) may be used for fine ballast, and a tamping pick (fig. 92) for broken stone. The tie is nipped up, as in new work, and the tamping is tight under the rails and snug only at the middle. Surfacing will be required in the spring if the track is on dirt or gravel ballast, and in any kind of ballast if the drainage is not good and the frost is deep. If there are especially bad spots on the section, they should be attended to first; otherwise, it is best to begin at one end and work continuously to the other. Send men ahead to set up bolts, nip up ties, and set spikes, and, if necessary, to gauge the track, so that when the surfacing gang follows it has nothing to do but line and tamp. With tamping bars, two men should work on a tie opposite each other, striking simultaneously. In cold climates, it may be necessary to use shims for surfacing during the winter, in which case they should be removed as rapidly as possible in the spring. These are blocks of wood of various thickness which are inserted between the rail and the tie to bring the rail to surface when the ballast is frozen too hard to be worked.

175. Renewing ties.—To renew a tie, draw the spikes with a claw bar (fig. 92), dig out under the tie until it drops clear of the rail, strike a pick in one end, and draw the tie out. Slip the new tie in its place, spike and tamp.

176. Renewing rails.—To renew a rail, have the new one alongside the old one, and see that it is of the right length. Draw or loosen the inside spikes, and when all is ready slip the old rail out of place and lift the new one in. Set part of the inner spikes as quickly as possible, and the rest before the first train passes, if possible. Be sure that the old rail is not disturbed until everything is ready. Figure 92 shows the usual form of spike maul. Its average weight is 8 pounds. The handle should be 3 feet long and in driving the hammer should be swung at the full length of the handle. Figure 92 shows a track chisel. Its average weight is 4 pounds. It is used with a short handle, which must not be tight in the eye. In frosty weather a chisel should be warmed before using. A little oil will make a chisel cut faster and last longer. In addition to keeping the cutting edge properly sharpened, the struck end should be cleaned up and trued whenever it becomes ragged or battered.

177. Relaying rail.—A party should work on one line of rail for, e. g., half a day and then move back to the other rail. A long line of old rail may be lined out at one time, but in placing the new rail the best results are obtained by laying it rail by rail. In an emergency it may be bolted together and then lined in, but it is difficult to make the proper provision for expansion with this method. A test may show that it is necessary to pull only one line of spikes on each rail, even when the new rail is of different weight and section, and still obtain the proper gauge. This saves time and material. After the old rail is thrown out, old spike holes should be plugged and ties adzed, as necessary, to give a solid bearing for the new rail. To allow a train to pass, a temporary connection may be made by use of a switch point. Bolt the switch point to the new rail and spike the toe of the switch point to gauge against the old rail. A connection of this kind should not be left in the track over night, or without a flagman who will make trains reduce speed over it. Old spikes, if undamaged, may be used again, but should be heated in a fire to remove oil or heavy rust.

178. Maintenance of switches.—Daily inspection, adjustment and oiling of switches, and taking care of lamps are done by a trackwalker. Switches should be inspected for signs of spread track through the turnout. The test for this is to observe whether the spike heads have been pushed out by the spreading of the rail, and by testing with a track gauge. In case spread track is found, spikes must be pulled and reset in firm timber. Moving tie plates to allow resetting is generally necessary. Switches should also be inspected for adjustment of points. Points must fit up to the stock rail with a tolerance of onesixteenth of an inch. A throw of less than 3½ inches is dangerous on account of the possibility of a flange of a wheel striking the switch point. Slide plates under the switch should be kept clean by sweeping, and they should be oiled. Switch stands should be inspected to see that there are no broken parts about them and that the switch lock is in place. The head and back rods should be inspected to see that the creeping of the rail has not forced them against the switch ties, thus interfering with the throwing of the switch. The main line and turnout tracks should be tested for gauge at the frog, as tight gauge in either track at the frog may cause derailment. Guard rails must be examined to see that they are fitting properly, that there are no broken parts, and that they provide flangeway not in excess of 1¾ inches at the middle of the guard rails opposite the frog point. All rail joints through the turnout should be inspected and bolts tightened when they are found loose.

179. Maintenance of signals.—Signals, such as switch targets, semaphores, and switch lamps, are inspected and maintained by a track walker. Maintenance consists of cleaning and refilling lamps, seeing that they are properly focused, polishing the glass lenses and observing and operating switches to see that they are in working order. Lamps should be refilled and cleaned once a day.

180. Maintenance of bridges.—Bridges should be carefully inspected periodically by qualified bridge inspectors, as explained in chapter 2.

181. Maintenance of water supply.—When a wooden water tank is found to be leaking badly there are a number of ways of effecting repairs of a more or less permanent nature. If the tank has not been used for some time and is leaking through the seams excelsior or sawdust will be found effective if used in the following manner: Fill the tank as full as possible and then dump into it any available sawdust or excelsior. This material will float on top of the water. The tank is then allowed to drain; as the water level recedes, sawdust or excelsior are drawn into the seams where it lodges. The tank is then refilled and the staves are allowed to swell, the excelsior or sawdust acting as caulking. Where bullet or worm holes occur these holes can be stopped by driving soft wooden plugs into them from the outside. Where an area is riddled by worm holes, rot or other causes, repairs can best be made from the inside by tacking to the affected area a sheet of rubber made from an automobile inner tube. Where the wooden floor of the tank is leaking badly due to the floor sills being old or decayed allowing the bottom of the tank to settle and the seams to open, the best quick repair is to raise the foot valve inside the tank about 6 or 8 inches above the bottom, apply reinforcement of small iron rods or pipe, and pour 6 or 8 inches of concrete into the bottom of the tank.

182. Suggested list of tools and supplies required for track maintenance.

TOOLS

6 Adze, railroad.
2 Axe, single bit, handle. 4-pound.
8 Bar, claw, 60″.
2 Bar, crow, 60″.
12 Bar, lining, diamond-point.
12 Bar, lining, wedge-point.
12 Bar, tamping.
2 Barrow, wheel-.
1 Bender, rail.
1 Bit, auger.
4 Bit, track.
1 Brace, ratchet.
16 Broom, rattan.
3 Can, oil, 1-gallon.
3 Can, oil, 2-gallon.
2 Can, oil, 5-gallon.
2 Car, section, hand.
2 Car, section, push.
3 Chisel, hand, cape.
3 Chisel, hand, diamond.
3 Chisel, hand, flat.
2 Chisel, rivet, handled.
12 Chisel, track.
2 Derail.
2 Drill, track.
2 Drum, 55-gallon.
2 File, mill, single cut, bastard, 12″.
2 File, flat, double cut, second, 12″.
2 File, saw, slim taper, 6″.
2 Filler, lamp, 1-pint.
4 Flag, railway, red.
2 Flag, railway, yellow.
12 Fork, ballast.
4 Fork, rail.
4 Gauge, track.
8 Goggles, chipping.
2 Grinder, bench, hand.
2 Hammer, machinist, ball pein, handled, 24-ounce.
2 Hammer, machinist, ball pein, handled, 2½-pound.
2 Hammer, track walker.
6 Handle, file.
2 Hatchet, 4″.
4 Hook, brush.
6 Jack, track.
2 Jack, universal.
2 Lamp, acetylene, portable.
4 Lantern, railway, red.
16 Lantern, railway, white.
2 Level, track.
2 Line, chalk.
4 Mattock.
12 Maul, spike.
4 Oiler, squirt, ½-pint.
12 Pick, clay.
16 Pick, tamping.
2 Pin, drift.
2 Puller, spike.
2 Punch, center.
2 Rule, folding, steel, 36″.
2 Saw, crosscut, two-man.
2 Saw, hand, crosscut.
2 Shovels, scoop, D handle.
6 Shovels, round point.
16 Shovels, square point.
2 Sledge, double face, handled, 16-pound.
2 Square, carpenter.
6 Stone, whet.
2 Tape, steel, 25-foot.
8 Tongs, rail.
8 Tongs, tie.
1 set Tools, packing.
2 Wrench, car, ½″ x ⅝″.
2 Wrench, car, ¾″ x ⅞″.
2 Wrench, car, 1″ x 1⅛″.
2 Wrench, track, double head, ¾″ x ⅞″.
12 Wrench, track, single head, ⅞″.
2 Wrench, screw (monkey), 12″.

SUPPLIES

10 Anchor, rail.
54 Bar, splice, 85-pound rail.
1 keg Bolt, track, ¾" x 3¾".
1 keg Bolt, track, ⅞" x 4¼".
17 Brace, rail, 85-pound.
80 cks. Carbic.
2 doz. Chalk, carpenter, white.
1 Frog, 85-pound rail.
25 Fusee.
1 Globe, lantern, railway, red.
3 Globe, lantern, railway, white.
5 lb. Grease, cup, No. 3.
2 Handle, axe, single bit, 36".
24 Handle, hammer, blacksmith, 16".
4 Handle, hammer, machinist, 14".
2 Handle, hatchet, 14".
20 Handle, maul, spike, 36".
40 Handle, pick, 36".
4 Handle, sledge, 36".
4 pr. Lens, goggle, chipping.
25 gal. Kerosene.
300 gal. Gasoline.
5 gal. Oil, car.
8 gal. Oil, motor.
¼ lb. Packing, valve stem.
48 Plate, tie, 85-pound rail.
1,000 Plug, tie.
28 Rail, 85-pound, drilled.
1,000 Shim, rail.
4 keg Spike, track, 9/16" x 5½".
1 Stand, switch, low.
1 Switch, 85-pound rail.
200 Torpedo.
½ keg Washer, lock, ¾".
1 lb. Wick, lantern.
1 keg Washer, lock, ⅞".
240 Tie, hewn.
1 set Tie, switch.

TOOLS, SIGNAL

2 Belt, lineman.
2 Climbers, lineman.
2 Cutter, wire.
2 Pliers, side cutting.
2 lb. Tape, friction.

PERSONNEL EQUIPMENT

3 Barrel, water.
3 Bucket, G. I., 14-quart.
3 Dipper.

SECTION VI

LIGHT RAILWAYS

183. General.—*a*. Light railways are used in forward areas to distribute supplies from the most advanced standard gauge railhead, or canal head, to the fighting troops at points as far forward as the tactical situation will permit. They are especially useful in carrying forward lines of supply during and following a strong offensive.

b. Light railways are more economically constructed and operated than highways and require from one-quarter to one-half of the material needed for the construction of standard gauge railroads.

c. Under conditions existing at the front, the construction of a light railway should proceed at the rate of about 1 mile per day, and might, under favorable conditions and with proper organization, be increased to 3 miles per day. The progress made in the construction of a macadam road under similar circumstances would not exceed ⅓ mile per day.

184. Principles of construction.—*a.* The location of a light railway is determined by its availability for the distribution of ammunition, road material, rations, water, engineer material, etc., and its possible means of access to objectives within the enemy's lines.

b. The process of location of a light railway does not differ from that described above for the location of a standard gauge road. The survey is carried forward with a view to securing the

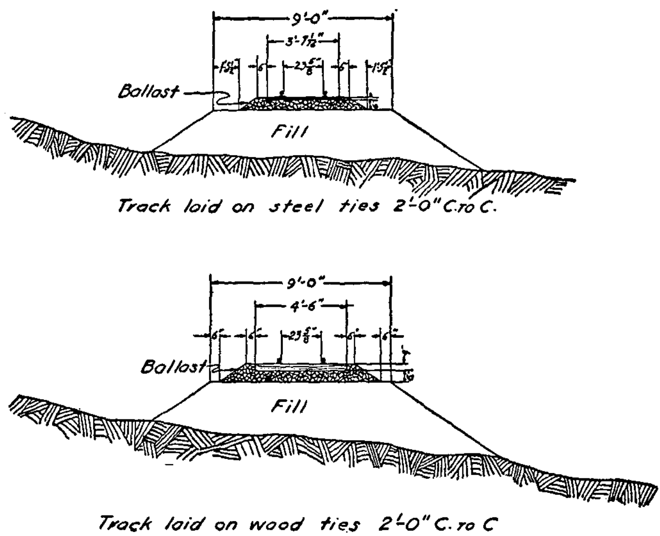


FIGURE 95.—Section of 60 cm roadbed on embankment

lightest gradients and curvatures which the topography of the country affords, keeping in mind a minimum of work and the rapidity of construction. The lines should be defiladed from enemy observation and kept as inconspicuous as possible.

185. Alignment.—Curves should be as light as can be fitted to the ground, to give a minimum of excavation and embankment; curves sharper than 165 feet radius (35½°) should be avoided if possible, and sharp curves should not be located at the foot of long steep grades; curves in opposite directions should have a minimum of 50 feet of tangent between curve points.

186. Grades.—*a.* The maximum grade should, if possible, be limited to 3 per cent; in any case, it should be as easy as the topography of the country permits, keeping in mind that there should be no deep cuts or high embankments, as these two conditions will prevent rapidity of construction. Compensate for curvature on grades at the rate of 0.02 per cent per degree.

b. On embankments the roadbed should be graded with a crown 9 feet wide, sides sloped 1½ to 1, with a berm 4 feet in

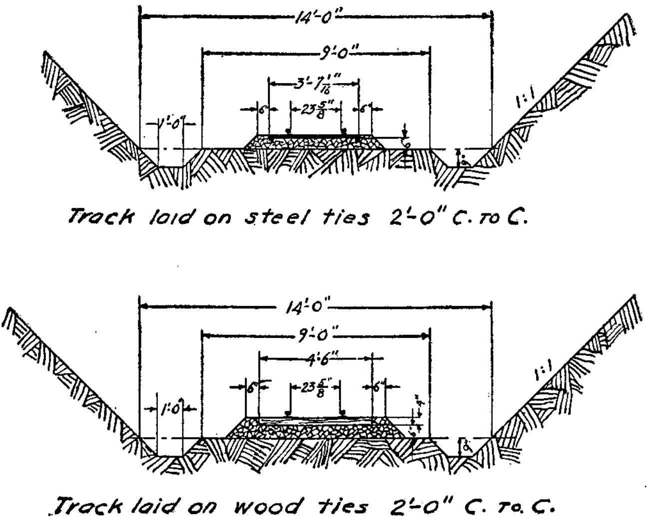


FIGURE 96.—Section of 60 cm roadbed in excavation

width between the toe of the slope and the edge of borrow pit. (See fig. 95.)

c. In cuttings, the width of the roadbed on the subgrade elevation should be 14 feet, with a ditch on each side 2½ feet wide at top, 12 inches wide at bottom and 9 inches deep, which will give a finished roadbed 9 feet wide. Slopes of cuts should be generally 1 to 1 in earth and ¼ to 1 in rock; the exact slope should be governed by the kind of material encountered and should be as steep as will stand without caving or slipping. (See fig. 96.)

d. Surface ditches should be provided on the high sides of cuts sufficient to lead surface water to the nearest borrow pit or other opening. In long borrow pits it is desirable to provide a sump pit about 4 feet by 4 feet. These should, if possible, be dug to a porous strata.

187. Track.—*a.* Track center stakes should be given for the beginning and ends of curves, 25 feet apart around the curves and 50 feet apart on the tangents.

b. The track consists of rails, weighing 25 pounds per yard, made up in sections, with steel ties secured to the rails by bolts and clips. It may be received in separate parts, in which case it must be assembled before laying on the grade. For this purpose assembly yards should be provided and equipped with benches, templates, gauges, tools, etc., and assembled sections should be shipped to depots in forward areas.

c. Track may be laid in place on wooden ties 4 inches by 6 inches by 4 feet 6 inches long, spaced 2 feet centers.

188. Operation.—Light railways may be operated in general accordance with the rules for operating standard gauge railways. A system of telephonic signal control is established. The length of run in one direction rarely exceeds 10 miles. Trains running toward the front are considered superior. At meeting points the inferior train takes the siding unless otherwise directed.

TABLE LIV.—*Light railway*

(Standard 60-centimeter track section, steel ties; length of section, 5 meters=16 feet 4⅞ inches)

Material	No.	Dimensions		Weight			
		Feet and Inches	Meters	Each		Total	
				Lbs.	Kilos	Lbs.	Kilos.
Rail	2	16′ 4⅞″	5	136.7	62.005	273.40	124.012
Ties, steel	8	1³⁄₆₄″ x 5½″ x 37¹⁄₁₆″.	0.005 x 139 x 1.094	17.1	7.756	136.80	62.048
Fishplates	4	1¹⁄₃₂″ x 1¾″ x 16⅛″.	0.0087 x .0444 x .409	2.92	1.324	11.68	5.296
Track bolts	8	½″ x 2⅛″	0.0127 x .0539	0.21	.095	1.68	.760
Rail clips	32	1¹¹⁄₁₆″ x 4⅝″	0.0428 x .1174	0.83	.376	26.56	12.032
Clip bolts	64	½″ x 1⅜″	0.0127 x .0349	0.17	.077	10.88	4.928
Total						461.00	209.076

TABLE LV.—*Light railway*

(Quantities of materials, except ballast, for 1 mile of single track)

Material	Description	Size	Quantity
Rail	25 lbs. per yard	30-foot [1] lengths	355 pieces, 43.7 tons.
Ties	Wood	4" x 6" x 4'6"	2,640 pieces.
Splice bars	4 hole	1¾" x 16⅛	710 pieces.
Bolts	930 per keg of 200 lbs.	½" x 2⅛"	1,420 bolts, or 1.6 kegs.
Spikes	746 per keg of 200 lbs.	7/16" x 4"	10,560 spikes, or 14.4 kegs.

NOTE.—The above materials weigh 85 tons.

[1] Ninety per cent in 30-foot lengths; balance in shorter lengths of not less than 24 feet.

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