GENERAL SPECIFICATIONS

FOR

FOUNDATIONS AND SUBSTRUCTURES

OF

HIGHWAY AND ELECTRIC RAILWAY BRIDGES.

ILLUSTRATED.

1902.

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Specifications for Foundations and Substructures of Highway and Electric Railway Bridges, 1902, .	$1.00
Specifications for Steel Highway and Electric Railway Bridges, 1901, ...	0.50
Specifications for Steel Railroad Bridges, 1901, . .	0.50

SENT BY MAIL, POSTPAID, ON RECEIPT OF PRICE.

PREFACE.

Standard specifications for the superstructures of highway bridges, giving the proper loadings, methods of proportioning and character of workmanship are readily obtainable. But for the foundations and substructures of such bridges, there is no standard practice or set of rules.

The author has herewith endeavored to illustrate the more common forms of substructures and foundations suitable for highway bridges and give the required proportions for all ordinary cases, with instructions and specifications for their construction.

Standard proportions and specifications for the substructures of highway bridges will not only broaden the competition for their construction, but will result in obtaining a better class of substructures than has generally been the case heretofore. They will also enable in many cases the local artisans to proportion and build the same.

The author excludes from consideration, difficult foundations in deep water or those requiring pneumatic or other special appliances or works of such expense as would demand especial study of the conditions to determine the best or most economical solution; also city bridges and long span bridges, where a higher and more elaborate class of substructure may be demanded and justified.

General Specifications for Foundations and Substructures

OF

Highway and Electric Railway Bridges.

PART I.

PRELIMINARY FACTS.

The proper determination of the character and location of the piers and abutments for a bridge at any particular locality requires a careful judgment, based upon a knowledge of the conditions of the stream during its varying stages of low and flood water; the action of the ice and flood trash; the liability of the banks and bottom to scour; the character of the bottom as to its bearing capacity and the possible presence of poorer material below that which is visible or can be reached by ordinary means of examination.

In cases, therefore, where the local knowledge of the river and the material of its banks and bottom is not complete and certain, a special examination should be made by an experienced engineer.

The author therefore assumes that either from local knowledge or by a special examination, the character of the bottom upon which the piers and abutments are to rest and the action of the stream at its various stages are known.

For any particular crossing, the best arrangement of spans for economy in first cost and for future maintenance will depend upon the proper placing of the piers and abutments and the selection of the kind of piers best suited to the conditions.

In many cases the location of the piers and the length of the spans are determined by the natural conditions of the banks and bottom or by the necessities of the waterway, for the navigation of boats or rafts or on account of flood trash or ice floes.

In cases where there is liberty to select such spans as may be most economical for the situation, Appendix A will give the method by which the economical arrangement of spans may be determined.

CHARACTER OF THE BOTTOM.

1. The material of the bottom upon which piers and abutments must be founded may, for the purpose of these specifications, be divided into the following general classes:

Rock.

Hard ground, as hard-pan, gravel, compact sand or hard dry clay.

Soft ground, as soft or wet clay, silt or mud, whose sustaining power must largely depend upon the frictional resistance of long piles or piles driven through the soft material to an underlying material of a harder character.

PREPARATION OF FOUNDATIONS.

First. Where they are above the water or where the water can be excluded or diverted by earth or timber dams (Plate I, Fig. 1).

2. **Rock.**—The site of the pier should be cleared of all the over-lying soil and other material, all the loose and disintegrated portions of the rock removed and where the surface of the rock is inclined, it should be leveled in steps to prevent any tendency of the piers to slip; all irregularities of the surface should be leveled up for starting the masonry, by filling them with concrete.

3. **Hard Ground.**—The material should be excavated to a depth below the action of frost or scour by surface currents, with a minimum depth of 3 feet, if above the water. And for foundations in the water, to a depth sufficient to be below any possible scour by the river currents (usually increased by the placing of piers in the stream) and to give the piers sufficient foothold to resist displacement by the shoving action of floods, ice or floating material.

4. Where the foundations are on or near the banks of

streams or on sloping strata they should be carried deep enough to ensure them from slipping by the sliding of this underlying material.

5. Where the material is liable to be softened, scoured or undermined by water action or where under water the foundations cannot be carried deep enough to be beyond any possibility of being affected by scour the bottom should be piled.

6. **Soft Ground.**—The material should be excavated to a stratum of harder material or else it must be excavated to a depth where the soil is permanently wet, if on land, and below possible scour, if in the water. Piles spaced not over 2½ feet centers should then be driven over the whole area to a "good refusal." The piles should be cut off or driven to one level and then covered with a timber platform or a layer of well-rammed concrete 2 feet thick, upon which to start the masonry. (See Plate 1, Fig. 1.)

7. In all cases as the masonry is built up, the remaining openings of the excavation should be refilled with good material well rammed in place.

8. **Second.** Where the foundations are under water which cannot be readily excluded or diverted by dams, some of the special methods of founding hereinafter described should be adopted.

GENERAL REQUIREMENTS.

9. No piles, timber or wood shall be used as an essential part of any foundation, above the water-line or in ground which is not permanently wet.

10. No iron or steel cylinders, beams, columns or other forms shall be used in direct contact with any kind of earth or soil, except where the use of piers with metal shells in deep water, and the use of disk or screw piles may be justified.

11. Wherever possible, all concrete and masonry must be laid in the open and not deposited through the water.

12. Preference will be given to such forms and methods of founding piers as do not require the concrete to be deposited through the water or the use of metal shells per-

manently exposed to oxydation by direct contact with the water and mud.

13. The tops of trestle or viaduct piers on land must be at least 18 inches above the surface of the ground.

14. Pedestal stones and bridge seats must be single stones or concrete blocks, and should have a superficial area double of that of the metal bearings resting upon them, with a minimum size of 18 inches square.

15. Where required, all anchor bolts and anchors shall be properly placed and built in by the masonry contractor, the material for the same being furnished in suitable time by the contractor for the metal work.

TIMBER AND PILES.

16. The timber and piles may be sound pine, spruce, hemlock or other woods equally good. They shall be free from wind shakes, large or loose knots, decay, worm holes, or other defects impairing their strength or durability.

17. The piles shall be at least 6 inches in diameter at the small end and not less than 10 inches in diameter at the butt for even the shortest lengths. They shall be of sufficient lengths to allow being driven to a "good refusal" under a hammer weighing 1,500 pounds falling freely 12 to 15 feet or its equivalent.

18. The minimum penetration accepted for the piles should be about 8 to 12 feet in wet gravel, sand or stiff clay, and 20 to 40 feet in soft clay or silt.

19. All piles in each foundation must be driven or else cut off to such a level, that no wood, including the platforms or grillages, will be above the permanent water line.

SPIKES.

20. Spikes for underwater platforms, grillages or cribs need not be headed, but may be cut from round or square bars to the required lengths and sufficiently pointed or sharpened at one end to allow their being driven readily; when the timber is dry or hard enough to require boring for the spikes, the holes must be bored $\frac{1}{8}$ inch less than the size of the spikes. The length of the spikes must be sufficient to pass through the first timber or timbers and enter

the last one at least 6 inches or its full thickness. The spikes should be $\frac{7}{16}$ square or $\frac{1}{2}$ round for timbers up to 8 inches in thickness and $\frac{5}{8}$ square or $\frac{3}{4}$ round for timbers 12 inches and over.

NOTCHING AND DOVETAILING.

21. The lateral resistance of cribs and wooden box piers (§§ 56, 86), against spreading must not depend solely upon spiking or nailing, but shall be secured by proper notching or dovetailing of the sticks together.

CEMENT.

22. The cement used for all mortar, concrete or masonry shall be an accepted and established brand of either Natural or Portland cement. It must be in good condition, perfectly dry and free from lumpiness and must be protected from moisture till used. Small pats made from either pure cement or from a mixture of cement and sand in equal proportions must set under water, hard and strong within 24 hours, be of a uniform color and show no signs of cracking or swelling.

SAND.

23. The sand used for all mortar and concrete shall be hard, clean, coarse and sharp; it must be free from particles of soft stone, earthy or alluvial matter. When used for mortar, unless free from pebbles or gravel, it must be screened. When used for concrete a moderate amount of small gravel or pebbles may be permitted.

CEMENT MORTAR.

24. Cement mortar will be made by thoroughly incorporating the cement and sand in the following proportions, viz., one barrel of 300 pounds of Natural cement and 12 cubic feet of sand, or one barrel of 375 pounds of Portland cement and 16 cubic feet of sand, with sufficient water to obtain the proper consistency.

GRAVEL AND BROKEN STONE.

25. The broken stone used for concrete must be hard, tough and sound stone, free from all dirt and earthy matter

and must not contain any stone exceeding 2½ inches in any dimension. Clean or washed gravel, free from all earthy matter, may be used instead of broken stone for concrete without screening. But an allowance must be made in the proportions of sand to be added, for the quantity of sand contained in the unscreened gravel.

CONCRETE.

26. The concrete must not be made faster than it can be properly placed in position. It shall be made on a close board platform. The materials for each batch must be carefully measured to ensure the correct proportions. The sand and cement shall be evenly spread and then thoroughly mixed by turning them over with shovels or hoes, before wetting; they should then be wetted and worked to a soft mortar; then the proper amount of broken stone or gravel, previously well drenched with water, should be spread over the mortar and well incorporated with the same by turning the whole over at least twice with shovels or hoes. The resulting mixture should be of such consistency as to quake slightly when rammed, but not before ramming. All concrete as soon as made should be placed in position in layers about 6 to 8 inches deep and thoroughly rammed till all the spaces are flushed with mortar.

27. If the mortar does not flush to the top under the ramming, the proportion of the stone must be reduced till this result is obtained. On the contrary if the material will not admit of proper ramming, being too quaky, more stone should be used in the mixture.

NATURAL CEMENT CONCRETE.

28. For foundations below the surface of the ground where the concrete will not be exposed to the action of running water or to the weather, the concrete shall be made of the following proportions: For each barrel of Natural cement, 12 cubic feet of sand and 24 cubic feet of broken stone or coarse gravel.

PORTLAND CEMENT CONCRETE.

29. For monolithic piers and abutments, for cylindrical and wooden box piers and for foundations where there is a

liability to the action of running water or where the bottom is soft or of unequal firmness, the concrete shall be made of the following proportions: One barrel of Portland cement, 10 cubic feet of sand and 20 cubic feet of broken stone or coarse gravel.

30. Pedestals and bridge seats may be made of concrete containing 1 barrel of Portland cement to 8 feet of sand and 16 cubic feet of broken stone or coarse gravel not exceeding three-quarters of an inch in their largest dimensions.

ROCK-FACED BROKEN-RANGE MASONRY.

31. All stone must be sound, durable and suitable in form for good bonding. All stone shall be laid on their natural beds and be rough squared on the joints, beds and faces, breaking joints at least 6 inches and with at least one header to every three stretchers. Headers shall be at least 3 feet long or extend entirely through the wall and be at least 15 inches in width. No stone shall be less than 6 inches in thickness or less than 12 inches on the least horizontal dimension. The work need not be laid up in regular courses, but shall be well bonded by the use of headers and stretchers. The stone shall be cleaned and dampened before setting and shall be laid in Natural or Portland cement mortar, as per § 24. The joints of each course must be completely filled with cement mortar before the succeeding course is laid. The joints must not exceed three-quarters of an inch in thickness.

32. No stone less than 12 inches in thickness or of a less superficial area than 12 square feet will be allowed in foundation footings, cutwater faces or the coping.

33. The bridge seats or that part of the coping which may be used for bridge seats shall be single stones not less than 12 inches thick and must be dressed level and true on the upper bearing surface.

ROCK-FACED COURSED MASONRY.

34. The stone shall be sound, durable and of an acceptable character for the locality. All stones shall be laid on their natural beds in regular courses. The face stones shall

be squared, jointed and bedded and laid in regular horizontal courses of not less than 10 inches in thickness, decreasing in thickness from the bottom to the top of the work. They shall consist of headers and stretchers not less than 3 feet long and 1½ feet wide, and shall have a breadth at least one and a quarter and a length twice the depth of the course. There shall be one header to every two stretchers and these shall be so distributed throughout each course and in alternate courses as to bond the work in the best manner. Each stone must bond with the stones of the underlying course; no bond of less than 9 inches will be allowed. All corners and batter lines must be run with a neat chisel-draft of 1½ inches on each face and the projection of the rock face must not exceed 3 inches.

35. The backing shall be either of cement concrete or of good-sized, well-shaped stones laid so as to break joints and bond the work in all directions.

36. The whole of the masonry shall be laid in Natural or Portland cement mortar, as per § 24. The joints of each course must be completely filled with cement mortar before the succeeding course is laid. The mortar joints must not exceed three-quarters of an inch in thickness.

37. The footing courses shall be large selected stone not less than 15 inches in thickness, nor of less superficial area than 15 square feet.

38. The coping shall be large selected stone, not less than 15 inches thick, nor of less thickness than the thickness of the average course in the body of the work. The tops and faces of the coping shall be bush-hammered and the mortar joints throughout must not exceed 3/8 inch.

39. Wing walls of abutments shall be capped with stone covering the full width and not less than 6 inches thick.

40. When directed, the wing walls shall be stepped and the cap stones dressed on the top surface and faces.

MONOLITHIC CONCRETE MASONRY.

41. These should be built within suitable molds, to the same sizes, forms and dimensions as for other classes of masonry, except all edges and corners to be chamfered and filleted at least one inch.

The molds should be built of plank and made sufficiently rigid to be practically unyielding under the ramming and tamping of the concrete. The sides in contact with the concrete should be smooth to give a good finishing surface to the concrete. The concrete must be of unquestioned good and selected materials and carefully and thoroughly mixed. (As the strength and homogeneity of monolithic masonry depends upon the cement, the strength and uniformity of all the cement used should be carefully tested and inspected by a competent person to see that it fully comes up to the standard requirements of the best Portland cement.) The concrete should be deposited in layers of 6 to 8 inches in thickness and be well rammed and consolidated before adding the next layer. The portion next the mold must be well cut in by spades, tamped and flushed to secure a full and smooth external surface. Special care is to be taken to insure the perfect adhesion of any new work, after the previous work may have taken a set, by roughening the old work by picks and giving it a thorough wetting before placing additional concrete.

42. Small stones, not exceeding one-man stone, well cleaned and thoroughly wetted, may be incorporated into these piers in the following manner: On any well-rammed layer such stone may be bedded in mortar composed of 1 part of Portland cement and 2½ of sand (1 barrel of cement to 10 cubic feet of sand), but no stones are to be closer together or to the molds than 6 inches or ⅔ the depth of the adjacent stones; the spaces are then to be filled with well-rammed concrete; before laying another layer of stone, the previous layer of stone must be covered by a layer of concrete of sufficient thickness to keep the stones in adjacent layers at least 6 inches apart.

43. The molds must not be removed in freezing weather or until the concrete has had forty-eight hours with the temperature above 40 Fahr. in which to set. The masonry should be thoroughly wetted every day and protected from the sun until at least one week after its completion.

44. After removing the molds the external surfaces, if not perfectly full and smooth, must be made so by troweling with cement mortar; the top surfaces must also be brought to a level in the same manner.

STEEL SHELLS FOR CYLINDRICAL OR OBLONG PIERS.

45. The plates for these shells shall be of soft or medium steel. For all parts below low-water the plates shall have a minimum thickness of $\frac{3}{8}$ of an inch, except where the outside is protected by concrete (Plate 7) it may be $\frac{5}{16}$. For parts between low and high water the minimum thickness shall be $\frac{5}{16}$ of an inch. For parts above high water, $\frac{1}{4}$ of an inch.

46. All circumferential seams should be single riveted, and all longitudinal seams double riveted. The pitch of the rivets shall be four diameters of the rivets for single riveting, and six diameters for each row of the double riveting. The rivets shall be $\frac{3}{4}$ or $\frac{7}{8}$ inch.

47. The shells shall be thoroughly painted, both inside and out, with two good coats of red lead and linseed oil paint, or some accepted waterproof preparation of acknowledged merit.

48. The oblong shells shall be properly and effectively braced against distortion by either the water pressure or the ramming of the concrete filling.

49. The bracing between a pair of cylindrical shells shall be sufficient to meet all the wind forces at the ends of the spans resting upon them. Where such braces will be subjected to the blows or entangling of floating materials, they must be protected by plank bulkheads or fenders.

50. The material, workmanship and proportions of such bracing shall be in accordance with Cooper's Highway Bridge specifications of 1901.

PART II.

GENERAL DESCRIPTION
OF
SUBSTRUCTURES
AND
METHODS OF FOUNDING.

TIMBER PLATFORMS, GRILLAGES, CAISSONS AND CRIBS.

51. To spread the loads and weight of the masonry over soft or unequal soil or to facilitate the founding of piers under water, it is often expedient to use timber platforms, grillages, caissons or cribs.

52. Timber platforms consist of two or more layers of closely-laid timbers alternately crossing each other and thoroughly spiked together to act as a solid platform. The thickness and size of each platform must be such as to distribute in a proper manner the full load over the piles, where used, or over the underlying material, without exceeding the carrying capacity of such material.

53. Timber grillages are similar layers of alternately crossing timbers laid with open spaces about the width of the timbers, so they can be weighted with gravel, stone or concrete, to facilitate the sinking and placing into position. They are generally floored top and bottom with plank.

54. Open caissons, the only kind of caissons here considered, are timber platforms or grillages with water-tight wooden sides attached thereto (usually so as to be removable after the work is complete), so as to form a water-tight box in which the masonry can be built in the dry; and which can be floated into place and sunk in proper position, either upon the pile heads or on the prepared bottom (Plate I, Fig. 2).

55. Timber cribs are formed of alternate longitudinal and transverse timbers, notched, dovetailed and spiked together at their crossings, so as to form a rigid structure

divided into a series of pockets several feet square. The open spaces of the ends and sides may be filled in with timber, so as to make them close and solid. A portion of the pockets are floored over so they can be filled and loaded with broken stone or concrete to sink the cribs into position upon the bottom or into the mud to a depth sufficient to get the desired stability. After the crib is in proper position the floored pockets should be loaded and the open pockets dredged until the desired depth is obtained. For hard bottom, where it is not possible to obtain a level surface by dredging, the ground should be carefully cross-sectioned and the bottom of the crib built to the correct shape to get a proper bearing.

56. No part of the cribs, grillages or platforms must extend above the permanent water-line.

57. Care must be taken that the upper parts of the cribs or grillages do not lift free from the loaded bottoms by buoyancy of the water, through faulty or deficient spiking.

58. After the cribs are sunk into position, if the crib is to be the only foundation for the masonry above, the open pockets are also to be filled with stone or concrete.

59. Such cribs are not recommended for bridge foundations, where other methods can be employed. But where other expedients prove too difficult or expensive, or where the bottom is of such a character that cribs may be placed without possibility of their future settlement or displacement by scour, they may be justified.

60. The difficulties attending their use for bridge piers, unless on hard bottoms, even when well and substantially made, are (1) their further settlement, either evenly or unevenly, after being loaded, thus throwing the work out of line and level; (2) their greater obstruction to the river currents and hence the greater liability to scour, owing to their increased size, over piers of more solid construction.

61. Cribs for bridge piers and abutments should preferably be made of square timber. Round timbers do not give as good bearings and fastenings; round timber cribs, as usually constructed, are more liable to distort and settle unequally, and also offer more resistance to the river currents.

62. Cribs may sometimes be used to protect and hold the footings of cylindrical piers on hard bottoms as will be hereafter described, Plate 7; or to give lateral stiffness to pile foundations in soft mud or deep water, Plate 9.

ABUTMENTS.

63. Abutments, in addition to supporting the bridge and its loads, must also hold back and protect the river banks and road filling. Generally to sustain the slopes of the banks and road filling and protect them from the scouring action of the currents, wing walls will be needed at both the upper and lower sides; their most favorable inclination to the direction of the stream must be determined by the local conditions. In some cases the abutments may be placed far enough back into the banks or the banks may be of such a character, that no wing walls will be needed. In other cases it may be sufficiently satisfactory to protect the banks by rip-rap, paving or piles sheathed with plank.

64. As the tendency of the material behind an abutment is to push it outward or to overthrow it on its footing, which would be greatly increased by any scour along or under the footing, the foundation should go well below any possible scour and be of a width sufficient to render it stable against such a tendency.

65. Generally abutments should be of stone or concrete masonry. The thickness of the masonry at any depth below the grade of the roadway should be four-tenths of such depth, down to the footing courses.

66. The footing courses, at least 2 feet thick, either of concrete or good large selected stone should project in front two-thirds of their thickness.

67. The thickness on top should be sufficient for the bridge seats and a back wall to sustain the roadway embankment. The coping should project at least 3 inches, but not more than one-third of its thickness.

68. The front batter should be 1 in 12.

69. Provision should be made, especially where wing walls are used, for drainage of the water in the banks behind the walls, by weep holes or other means.

70. As the masonry progresses the back filling must be replaced and consolidated by being well rammed in layers.

71. Plate 2 shows an abutment without wing walls, with the governing dimensions for bridges of different spans and widths. Plate 3 shows an abutment with wing walls. (See § 110).

72. Abutments may be built of rock-faced broken-range masonry, rock-faced coursed masonry or monolithic concrete masonry as previously described.

73. Where the foundation cannot be carried to good hard bottom below possible scour, the bottom should be piled with piles spaced not over 2½ feet centres, cut to a level; the spaces filled in with broken stone and the whole covered with a timber platform upon which to start the masonry; all the timber being kept below low water. (See § 6.)

MASONRY PIERS.

74. These will be built of either rock-faced broken-range masonry, rock-faced coursed masonry or monolithic concrete masonry as previously described. The body of the pier shall have a batter of 1 in 24 at the ends and at the sides. The coping should extend at least 3 inches all around, but not more than one-third of its thickness. The footing courses at least 2 feet thick, either of concrete or good large selected stone, should extend two-thirds of their thickness all around. The cut-water should extend 3 feet above high water line.

75. Plate 4 gives the dimensions for such a pier for spans of different lengths and widths. (See § 110.)

76. These piers should be founded below any possible scour by some of the usual expedients, viz., excavating inside of earth or timber coffer-dams, or sheet piling, or by some method of dredging. Or else piles, spaced not over 2½ feet centers, should be driven over the bottom and cut off to one level close to the bottom by an underwater saw and an open caisson whose bottom is a properly proportioned timber platform sunk thereon, and the masonry laid up therein in the open air.

DIAGONAL PIERS.

77. In quiet waters or where the piers will not be subjected to shocks of heavy ice or floating materials, two isolated piers placed diagonally to the stream may sometimes be substituted with advantage for a single pier.

78. Plate 5 shows the form and dimensions of such piers.

CONCRETE PIERS WITH METAL SHELLS.

Plates 6, 7 and 8.

79. For such piers either one oblong shell or two cylindrical shells braced together, can be used.

80. For soft bottom or where piles can readily be driven into the material of the bottom, the shells should be sunk into the ground well below any possible scour, by weighting the shells and excavating the material from the inside. The inclosed space should then be filled with piles of such lengths as will permit driving to a "good refusal," with their tops at low water level. The piles should be kept free from the metal shell 4 to 6 inches, and the spaces between the piles must be less than the size of the smallest pile used. For the oblong shells this close spacing need only apply to the end portions, symmetrical with the center of the bearings of the trusses. The spaces between and about the piles must then be well filled and rammed with Portland cement concrete. The shells above low water shall then be pumped dry and filled with Portland cement concrete, in well-rammed layers, to the top, where it must be finished off in proper shape for the bridge seats and drainage.

81. For material which can be excavated from the inside of shells to a sufficient depth below possible scour, but which does not need piling; the shells should be sunk to the proper depth, the bottom sealed against the admission of water by depositing concrete through pipes or in bags, then pumped dry and the interior properly filled with Portland cement concrete. Or, the bottom may be dredged beforehand to a proper level and the shells bolted rigidly to timber platforms or grillages and then sunk as open caissons.

82. For rock bottom, where it is possible to fit the platforms to the rock surface, this form may be used, but where

the weight of the piers is not sufficient to give abundant security against the shoving action of floods, ice or floating material the platforms should be anchored securely to the rock by anchor bolts.

83. For rock or hard bottom cylinder piers may be steadied and also protected from scour by a surrounding crib, as shown on Plate 7. After the crib is placed and sunk by filling the floored pockets with broken stone or concrete, the cylinders should be lowered into place through the open pockets provided for them ; then the open spaces outside of the cylinders should be well filled and rammed with Portland cement concrete to the full depth of the crib. Then the interior of the cylinders should be pumped dry and filled in the usual way with concrete. Where the crib cannot be sunk to the rock, owing to the overlying mud, sheet piles or sheeting can be driven around the periphery of the open pockets to the rock and the mud removed, before placing the cylinders or depositing the concrete.

84. The permanency of the wooden crib in fresh water and the protection of the metal shell, both outside and inside, by cement concrete give this style a superiority over those where the outside of the shell is in direct contact with the water and hence subject to continuous oxydation.

85. Little or no faith should be put in the claim that when the metal shells do finally rust away, the concrete core will be able to serve the full purpose of a pier, even for the best concrete work; and when the concrete is deposited through the water as has been the usual custom heretofore it will probably be found to be no better than loose stone.

WOODEN BOX PIERS.

86. In many localities wooden boxes, as shown on Plate 10, can be advantageously substituted for the metal shells.

87. On account of their square form, they should be placed diagonally to the current. The timbers being entirely under water, will be permanent in fresh water, or where the waters are free from the *teredo* and *limnoria*.

88. The horizontal sticks should be notched over each other, and be spiked together at each crossing and to the

vertical corner sticks. Horizontal washboards at or near the level of the ground will reduce the undercutting action of the currents, and will also serve for loading with stone or concrete for sinking the boxes to place. It may be best in some cases to make the exterior flush by a series of vertical timbers spiked to the horizontal sticks.

89. For soft bottom these boxes may be placed in position, weighted and then sunk by excavating the interior till the proper depth is obtained. The inner space should then be piled and filled with concrete up to low water level; above that stone or concrete masonry must be carried up to receive the superstructure. In some cases it may be best to drive the piles or at least a few of them first and build the box in place around them.

90. For hard bottom where piles cannot be driven, a similar form of box or crib can be secured to a timber platform or grillage and sunk as an open caisson upon the prepared bottom, Fig. 2, Plate 10.

91. The upstream corners of these wooden boxes can, where considered desirable, be protected with an angle iron nose.

TRESTLE OR VIADUCT PIERS.

PIERS ON LAND.

92. These shall be built of stone or concrete masonry and capped with suitable pedestal stones (§14).

93. For gravel, sand or good hard bottom the base area of the piers should not be less than $3\frac{1}{2}$ feet square for spans up to 50 feet. This area should be increased 50 per cent. for moderately good ground and the bottom piled, if it is soft.

94. For double-track electric railway viaducts these areas should be doubled.

95. The tops of such piers are assumed to be only a moderate height above the ground; if it is found desirable to raise them considerably above the ground, the sizes must be increased accordingly, for a proportional strength.

PIERS IN THE WATER.

96. Any of the previously described forms and kinds of piers for use in water may be used for trestle piers.

97. In addition disk or screw piles, with shafts or columns of solid or hollow metal, wrought or cast, or of wood, may be used for this purpose. Below the mud line the shafts should preferably be of cast iron or timber.

98. The disks or screws must be of sufficient bearing area to support the loads properly, and the shafts must be considered as columns for their unsupported lengths and be proportioned as such. And in case of screw piles, the shafts and the fastenings to the screw must be proportioned to resist the torsion needed to force the screws into the ground.

99. **Disk Piles.**—Plate 11. These are used where the materials of the bottom can be penetrated by means of the water-jet. The disks must be sunk sufficiently below any possible scour, so as to have at all times a depth in the sand of 6 to 10 feet. For silt or soft material, the disks should penetrate to a good stiff bottom or else to a depth such as would be required for good piling in the same material.

100. The disks shall be of cast iron and of the sizes given in the tables for the particular span as proposed. The thickness of the metal in the top plate and thicker parts of the cone and connecting ribs should not be less than 1¼ inches for disks 24 inches diameter or 1½ inch for larger sizes. The cone and its ribs not only strengthen the disk, but are useful, when layers of clay or other tough material occur, to aid in penetrating them, by turning and dropping the pile.

101. The cone should have a tapered interior ending in a hole large enough to pass freely the water pipe, which should be at least 1½ inches diameter.

102. The shafts or columns should bear squarely and fully upon the tops of the disks and should be well secured to the same.

103. **Screw Piles.**—Plate 12. Although the extra cost of the screws and the greater difficulties and expense of founding screw piles render their use in most cases undesirable, cases do occur where their use is justified.

104. As experience has shown that in sinking such piles, it is a common thing to call into play the full torsional

capacity of the shafts at times, the thickness of the metal of the screws and all the connections should be proportioned for this expectation.

105. The best pitch for different materials is a matter of experience and judgment. In general it should be from one-third to one-sixth of the diameter of the screw, the larger pitch being for soft material and decreased as the material increases in toughness of penetration.

106. The points of the screws may be made of various forms to suit the material, which is to be penetrated, viz., gimlet pointed for gravel, serrated for soft rock or coral, blunt for sand or fitted for the assistance of the water-jet in sand or gravel. (See different forms shown on Plate 12.)

107. Experiment has shown that for driving screw piles with disks of 48 inches diameter into chalk rock, gravel or hard bottom, a torsional power of 125,000 lbs. feet was needed.

TABLES OF SIZES AND DIMENSIONS.

108. In order to render the plans as given herein of more general usefulness the author has omitted all data as to the loads allowed in different cases, and such other data as would be necessary to compute and design the substructures for each particular case.

He has considered that for the commoner kinds of highway and electric railway bridges it would be better to determine the proper dimensions for the various cases and present them in a tabular form.

He believes that he has not varied from what is considered good practice in the pressures used for good masonry, or the classes of soils considered or the carrying capacity of piles, screw piles or disk piles.

SIZE OF PIERS AND ABUTMENTS.

109. The dimensions and proportion of parts shown upon the accompanying plans and tables for piers and abutments of different kinds, for the span corresponding to that of the proposed bridge, shall be considered the minimum sizes to be used for such bridge.

110. The lengths shown on Plates 2, 3 and 4 are for piers and abutments of bridges without skew. For skew bridges these lengths must be proportionally increased.

LOCATION AND LEVELS.

111. The contractor must locate the foundations and construct the substructures at the exact distances, and to the correct alignment and levels required for the proposed superstructure.

PROPOSALS.

112. In making proposals for any work under these specifications, bidders must clearly state the kind of substructure, character of the masonry, depths of the foundations, length and kind of piles, kind of cement they intend to use, and such other facts as will enable a fair judgment and comparison of the several bids.

APPENDIX A.

ECONOMICAL NUMBER OF SPANS.

The total cost of a bridge at any particular crossing must include both the cost of the superstructure and the cost of the substructures and foundations. One additional span, by decreasing the length of the spans, decreases the cost of the superstructure, but by adding another pier increases the cost of the substructures. Where the cost of an additional pier equals the saving on the superstructure, either number of spans can be used without effecting the total cost.

In order to have a ready means of determining the proper number of spans for any crossing, where the local conditions admit of a choice, the diagram on Plate 13 has been prepared for different lengths of crossings and different costs for one river pier.

To provide for bridges of different widths the cost of one pier *per foot of clear width* is used; the clear width for highway bridges being the width of roadway and sidewalks, and for electric railway bridges, 14 and 26 feet for single and double track bridges.

The vertical column at the left hand of the diagram (scale of square roots) gives varying costs per foot of clear width for one pier, including towers, if there be any.

The horizontal line at the bottom gives the length of the crossings between centres of abutments (one scale for highway and one for electric railway bridges).

Having made an estimate of the cost of one pier (see Appendix B) of the required dimensions as per the specifications, divide it by the clear width of the proposed bridge. Then follow the horizontal line through this value to the vertical line through the length of the crossing and the number of spans given for that point will be the required number for economy.

Example: Crossing, 500 feet; width of roadway, 20 feet and two sidewalks, each 5 feet.

Should one pier cost $900 or $30 per ft. of width, use 7 spans.
" " " " $1,800 " $60 " " " " " 5 "
" " " " $4,000 " $133 " " " " " 3 "

APPENDIX B.

TABLE I.

Approximate Contents of One Masonry Pier. Plate 4.

see § 110.

Spans.	Roadways.	Depth of Piers, Feet. 10	15	20	25	30
100 ft.	12 feet	29	44	60	77	94
	20 "	38	59	82	108	136
	E, single T	31	46	62	80	100
	E, double T	50	75	102	132	166
150 ft.	12 feet	34	51	70	90	111
	20 "	46	70	95	125	157
	E, single T	37	54	74	96	120
	E, double T	58	86	118	153	191
200 ft.	12 feet	39	58	80	103	128
	20 "	53	80	109	143	178
	E, single T	43	63	86	112	140
	E, double T	66	99	135	174	217
250 ft.	12 feet	44	66	90	116	145
	20 "	61	91	123	160	199
	E, single T	48	74	98	127	159
	E, double T	73	109	149	192	238
300 ft.	12 feet	49	73	100	130	162
	20 "	68	101	137	177	220
	E, single T	54	80	109	142	178
	E, double T	80	120	164	210	260

Contents in cubic yards. Depth of pier from top of coping to bottom of footing.

TABLE II.

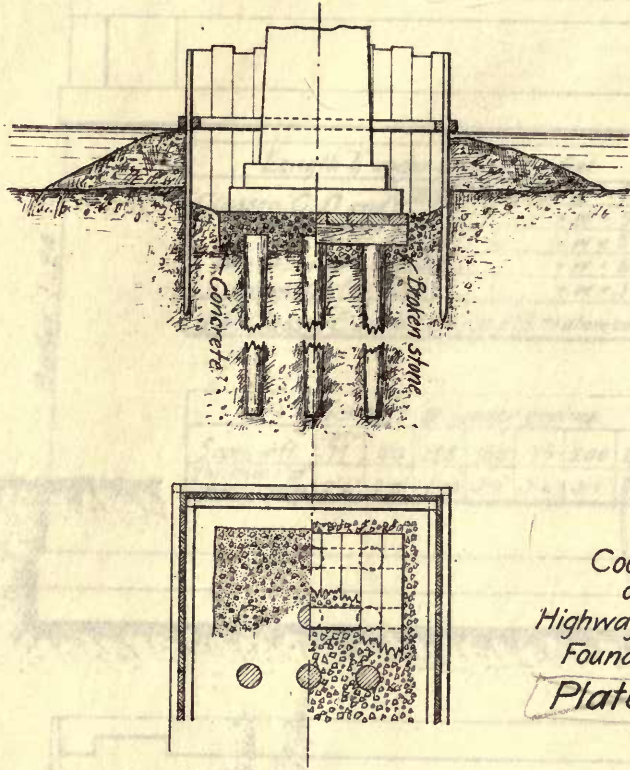
Approximate Contents of One Masonry Abutment, Without Wing Walls. Plate 2.

see § 110.

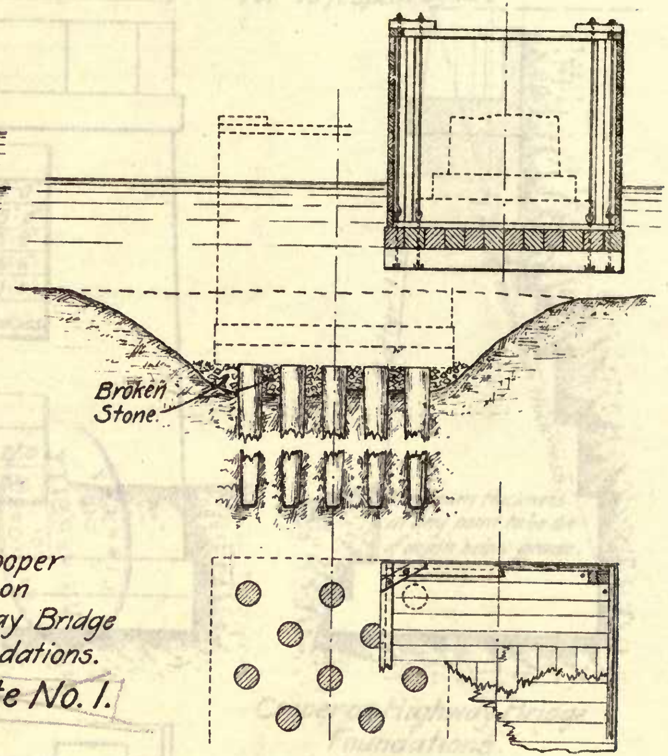
Spans.	Roadways.	Depth of Footing Below Grade, Feet. 10	15	20	25	30
100 ft.	12 feet	20	39	67	100	145
	20 "	28	56	95	145	206
	E, single T	21	44	75	112	160
	E, double T	36	72	120	183	260
300 ft.	12 feet	22	45	77	116	165
	20 "	31	63	106	161	227
	E, single T	25	50	85	128	181
	E, double T	49	84	141	210	296

Contents in cubic yards.

[H 9273.]



Sheet piled
COFFERDAM FOUNDATION.
Fig. 1.



FLOATING CAISSON
FOUNDATION.
Fig. 2.

Cooper
on
Highway Bridge
Foundations.
Plate No. 1.

Fig. 60 A

Ref. on note

APPENDIX B.

TABLE I.

APPROXIMATE CONTENTS OF ONE MASONRY PIER. PLATE I.

See § 112.

Spans.						
[illegible] ft.	11 feet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	20 "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	E. single T.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	E. double T.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
200 ft.	12 feet	24	[illegible]	[illegible]	[illegible]	[illegible]
	27 "	36	[illegible]	[illegible]	[illegible]	[illegible]
	E. single T.	37	[illegible]	71	[illegible]	[illegible]
	E. double T.	58	[illegible]	118	[illegible]	[illegible]
250 ft.	16 feet	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
300 ft.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
350 ft.	[illegible]	[illegible]	77	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	E. single T.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	E. double T.	95	150	184	[illegible]	[illegible]

Contents in cubic yards. Depth of pier from top of coping to bottom of footing.

TABLE II.

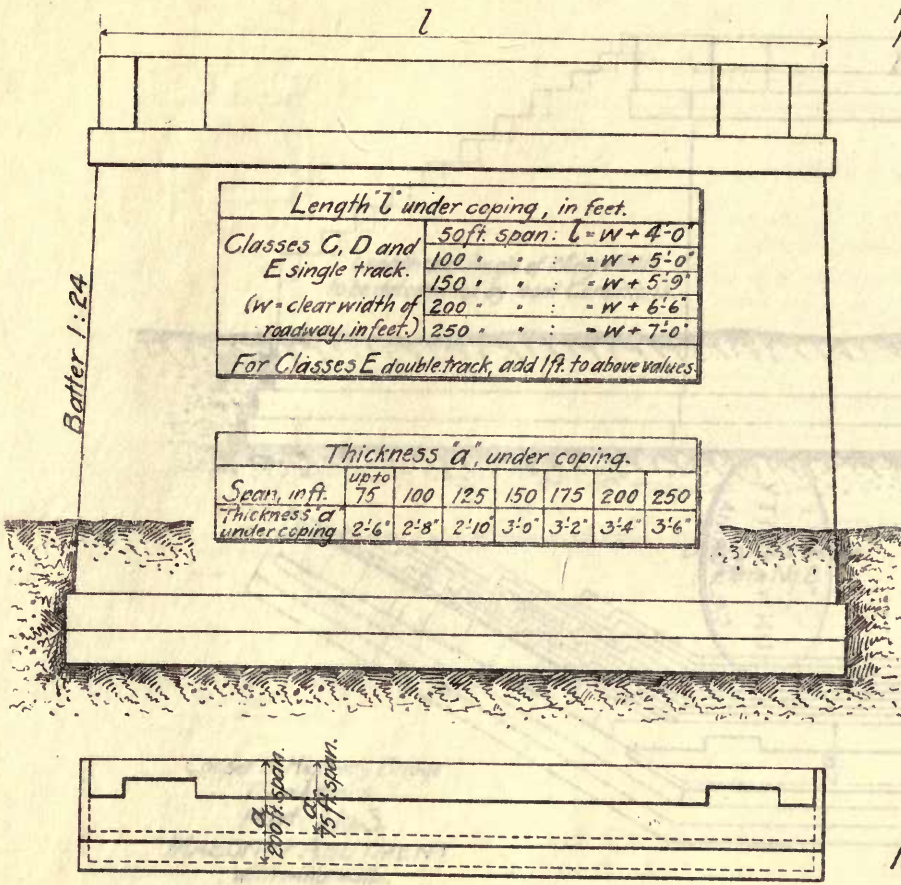
APPROXIMATE CONTENTS OF ONE MASONRY PIER WITHOUT [illegible]

[illegible] WALLS.

See § 118.

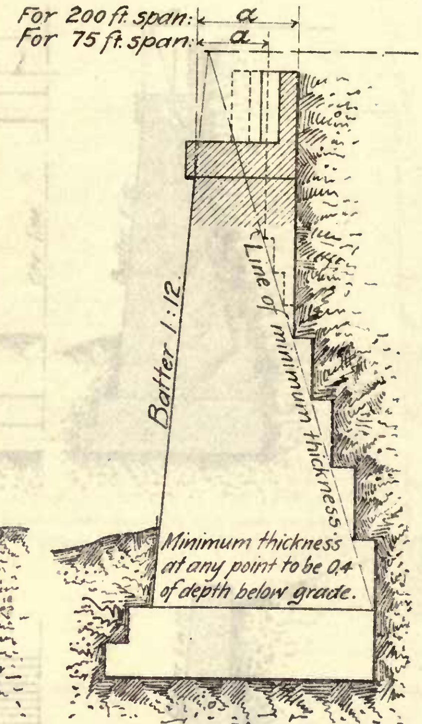
Spans.		Depth of Footing Below [illegible]				
		10	[illegible]	[illegible]	[illegible]	[illegible]
200 ft.	[illegible]	20	40	[illegible]	[illegible]	[illegible]
	20 "	28	50	90	[illegible]	[illegible]
	E. single T.	31	44	75	[illegible]	[illegible]
	E. double T.	38	72	120	[illegible]	[illegible]
300 ft.	18 feet	28	48	77	[illegible]	125
	30 "	37	63	100	[illegible]	167
	E. single T.	35	56	85	[illegible]	[illegible]
	E. double T.	49	89	131	[illegible]	[illegible]

Contents in cubic yards.



Length "l" under coping, in feet.		
Classes C, D and E single track. (w = clear width of roadway, in feet.)	50 ft. span:	l = w + 4'-0"
	100 " " :	= w + 5'-0"
	150 " " :	= w + 5'-9"
	200 " " :	= w + 6'-6"
	250 " " :	= w + 7'-0"
For Classes E double track, add 1 ft. to above values		

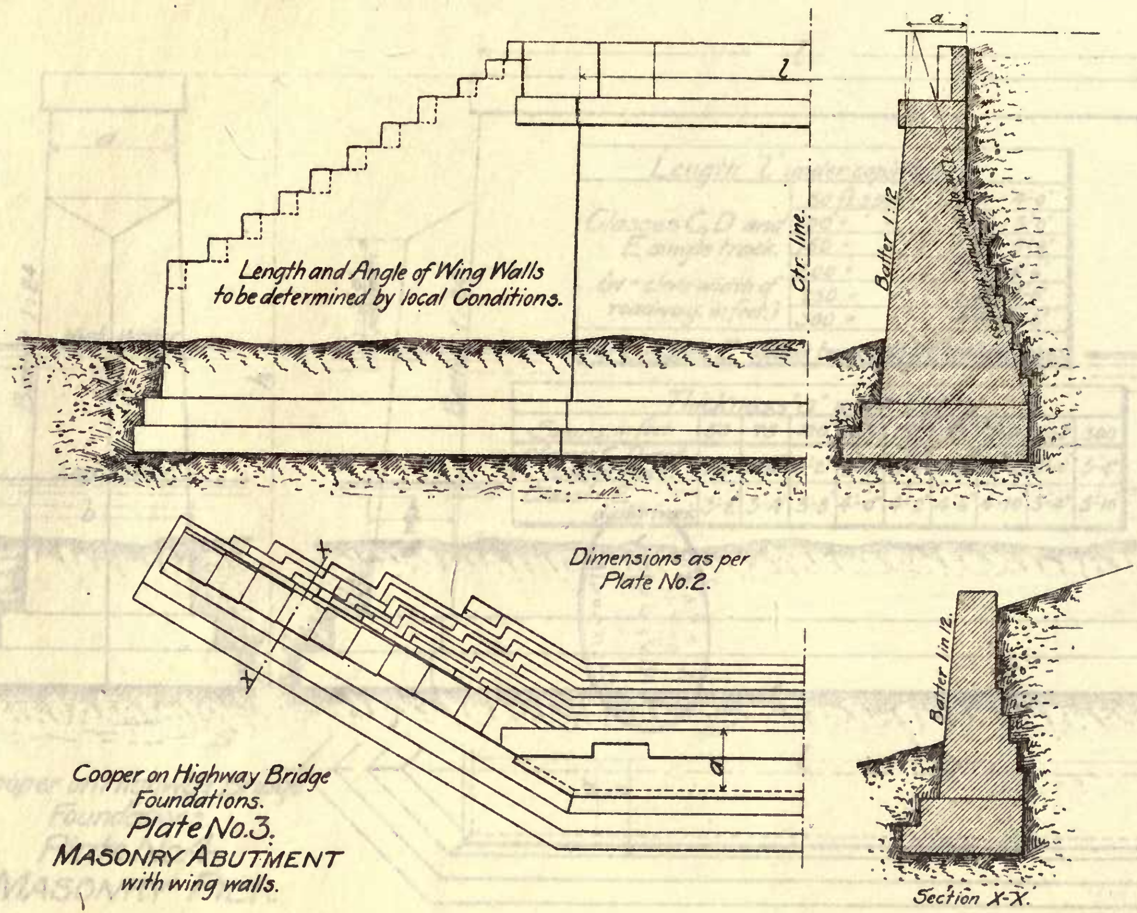
Thickness "a", under coping.							
Span, in ft.	up to 75	100	125	150	175	200	250
Thickness "a" under coping	2'-6"	2'-8"	2'-10"	3'-0"	3'-2"	3'-4"	3'-6"



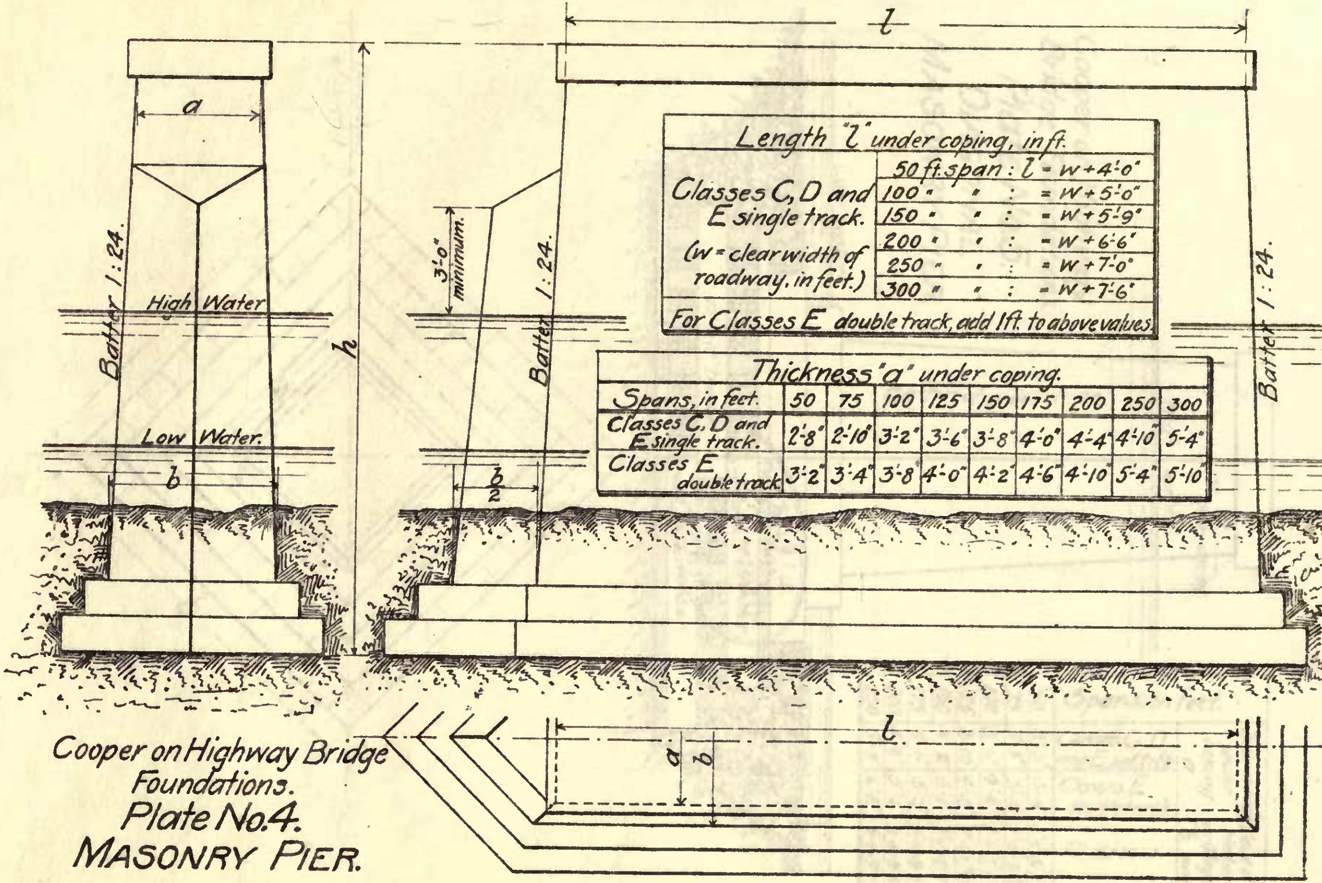
Cooper on Highway Bridge Foundations.

Plate No. 2.

MASONRY ABUTMENT without wing walls.



Cooper on Highway Bridge
Foundations.
Plate No.3.
MASONRY ABUTMENT
with wing walls.



Length "l" under coping, in ft.		
Classes C, D and E single track. (w = clear width of roadway, in feet.)	50 ft. span :	l = w + 4'-0"
	100 " " :	= w + 5'-0"
	150 " " :	= w + 5'-9"
	200 " " :	= w + 6'-6"
	250 " " :	= w + 7'-0"
	300 " " :	= w + 7'-6"
For Classes E double track, add 1 ft. to above values.		

Thickness "a" under coping.									
Spans, in feet.	50	75	100	125	150	175	200	250	300
Classes C, D and E single track.	2'-8"	2'-10"	3'-2"	3'-6"	3'-8"	4'-0"	4'-4"	4'-10"	5'-4"
Classes E double track	3'-2"	3'-4"	3'-8"	4'-0"	4'-2"	4'-6"	4'-10"	5'-4"	5'-10"

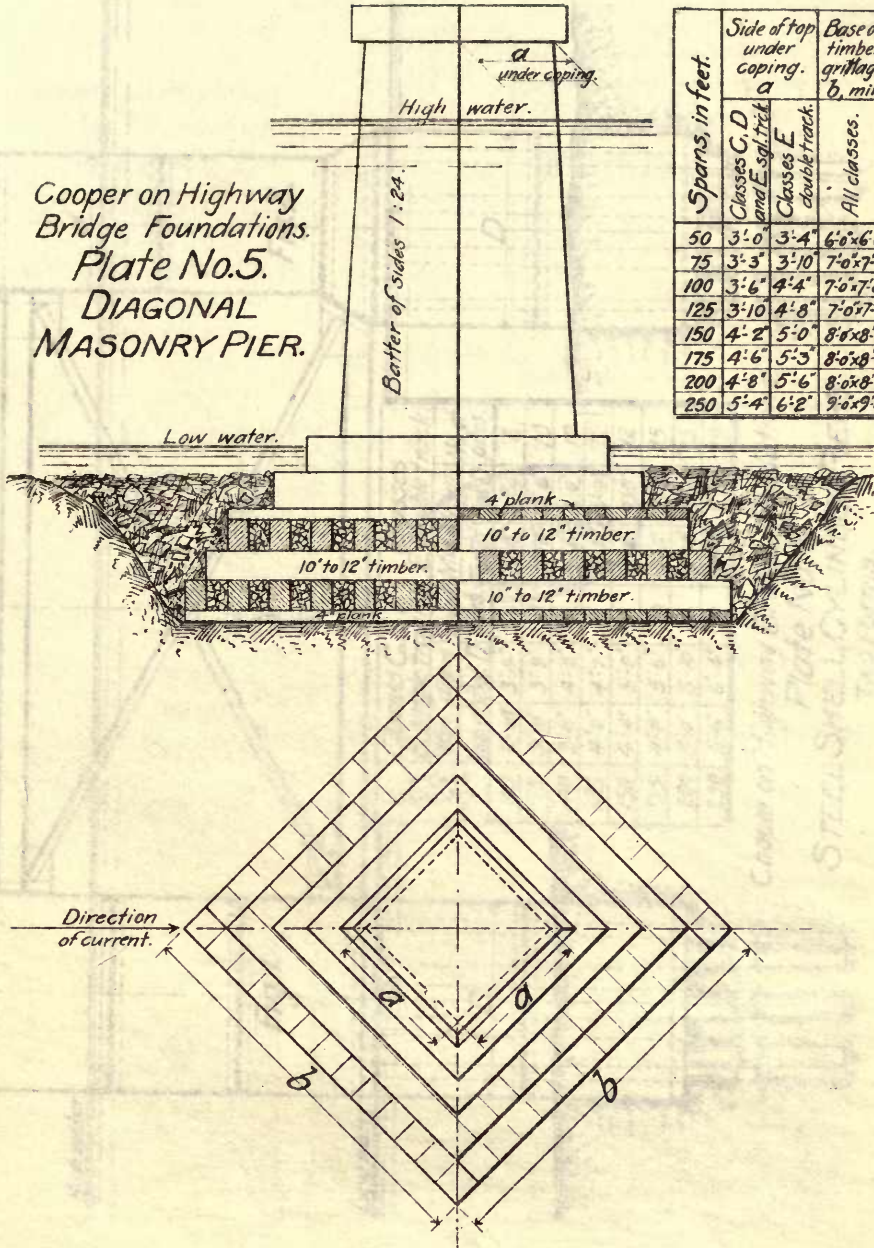
Cooper on Highway Bridge Foundations.
Plate No. 4.
MASONRY PIER.

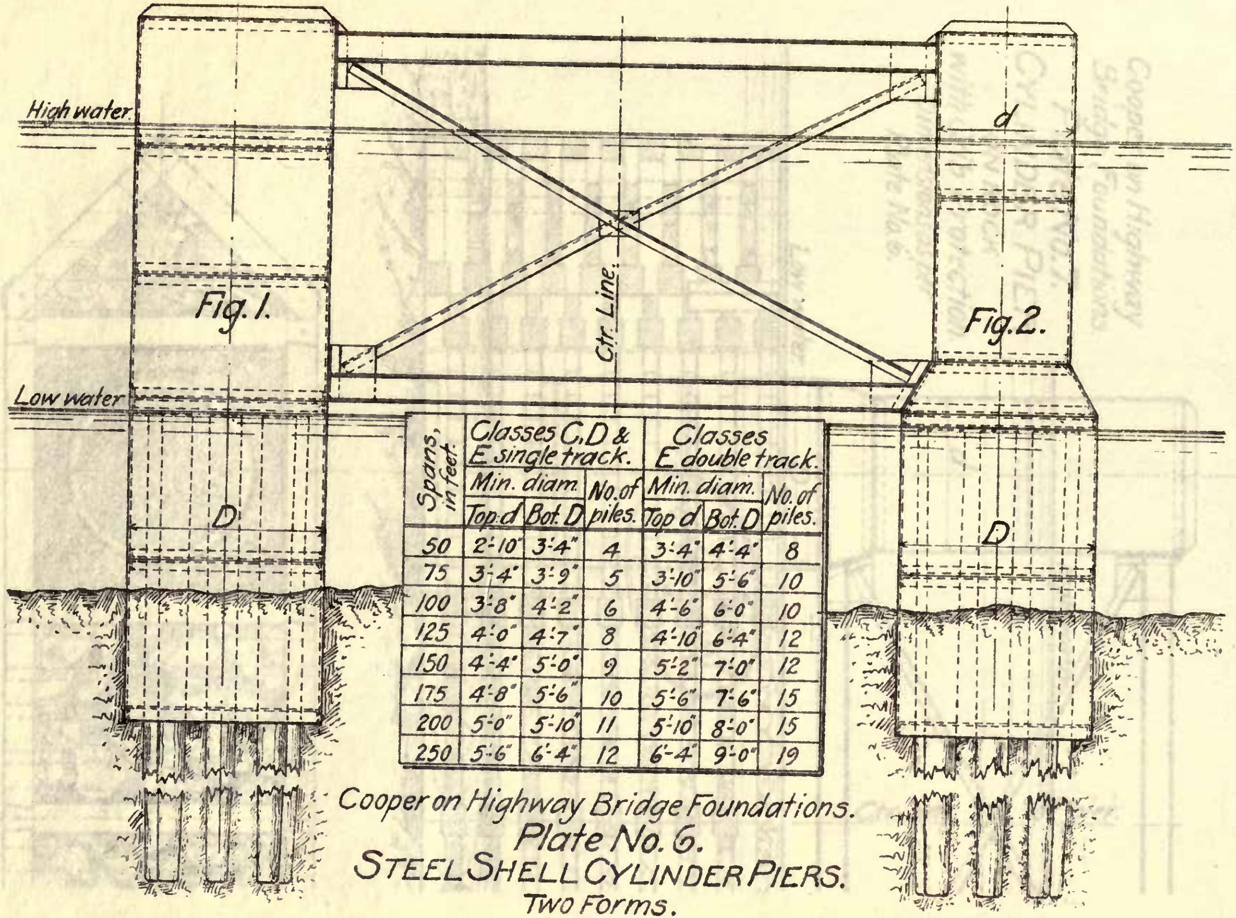
Cooper on Highway Bridge Foundations.

Plate No. 5.

DIAGONAL MASONRY PIER.

Spans, in feet.	Side of top under coping. a		Base of timber grillage. b, min.
	Classes C, D and E sgl. track	Classes E double track.	All classes.
50	3'-0"	3'-4"	6'-0"×6'-0"
75	3'-3"	3'-10"	7'-0"×7'-0"
100	3'-6"	4'-4"	7'-0"×7'-0"
125	3'-10"	4'-8"	7'-0"×7'-0"
150	4'-2"	5'-0"	8'-0"×8'-0"
175	4'-6"	5'-3"	8'-0"×8'-0"
200	4'-8"	5'-6"	8'-0"×8'-0"
250	5'-4"	6'-2"	9'-0"×9'-0"





Spans, in feet.	Classes C, D & E single track. Min. diam. Top d	Bot. D	No. of piles.	Classes E double track. Min. diam. Top d	Bot. D	No. of piles.
50	2'-10"	3'-4"	4	3'-4"	4'-4"	8
75	3'-4"	3'-9"	5	3'-10"	5'-6"	10
100	3'-8"	4'-2"	6	4'-6"	6'-0"	10
125	4'-0"	4'-7"	8	4'-10"	6'-4"	12
150	4'-4"	5'-0"	9	5'-2"	7'-0"	12
175	4'-8"	5'-6"	10	5'-6"	7'-6"	15
200	5'-0"	5'-10"	11	5'-10"	8'-0"	15
250	5'-6"	6'-4"	12	6'-4"	9'-0"	19

Cooper on Highway Bridge Foundations.

Plate No. 6.

STEEL SHELL CYLINDER PIERS.

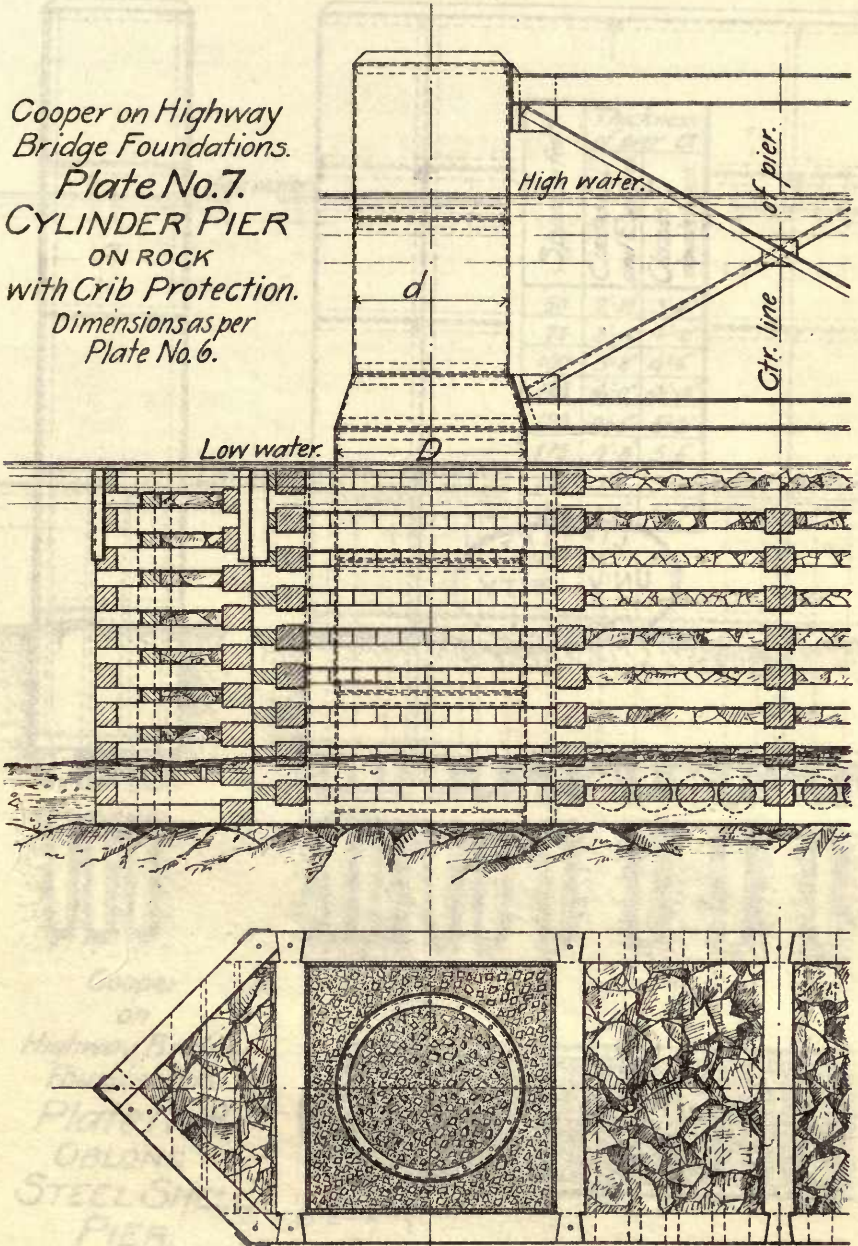
Two Forms.

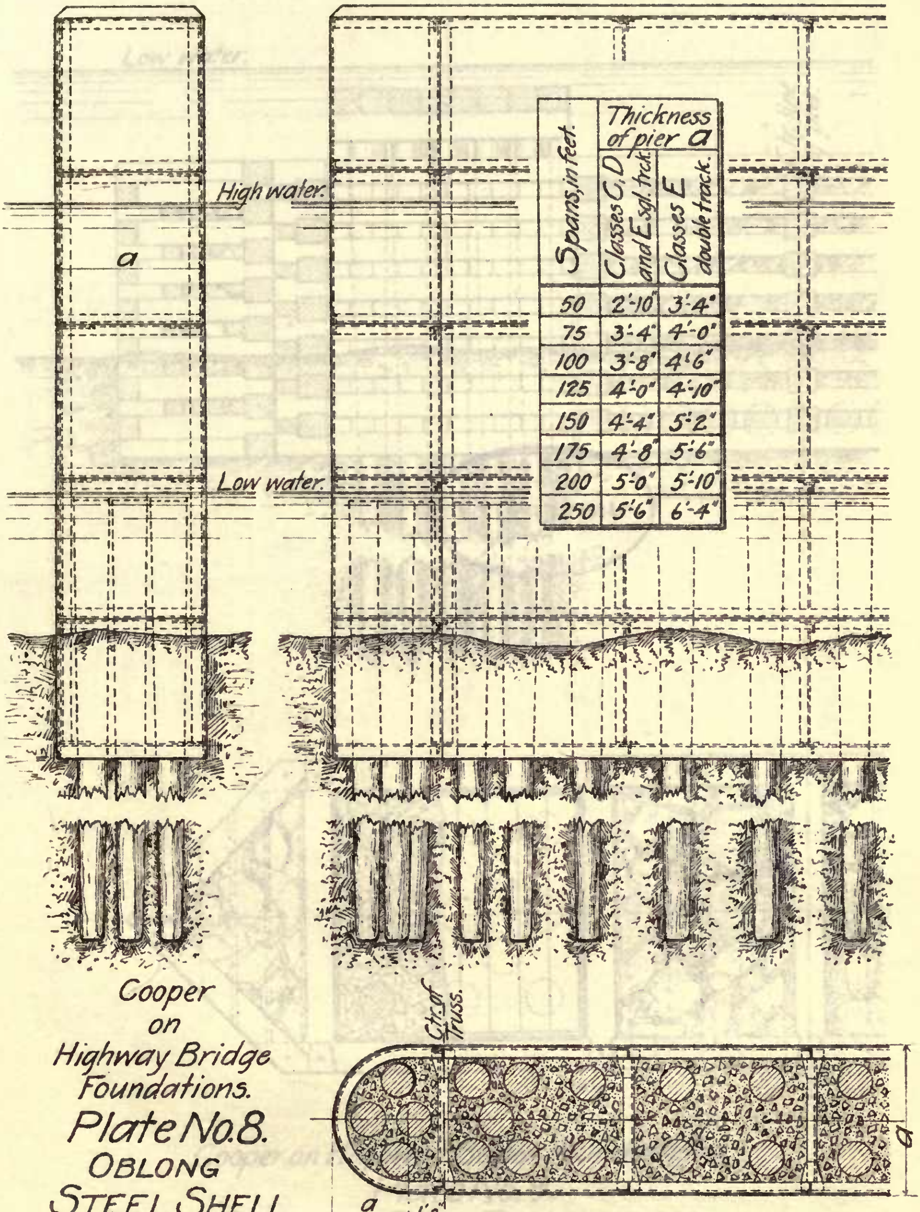
Cooper on Highway
Bridge Foundations.

Plate No. 7.

CYLINDER PIER
ON ROCK
with Crib Protection.

Dimensions as per
Plate No. 6.



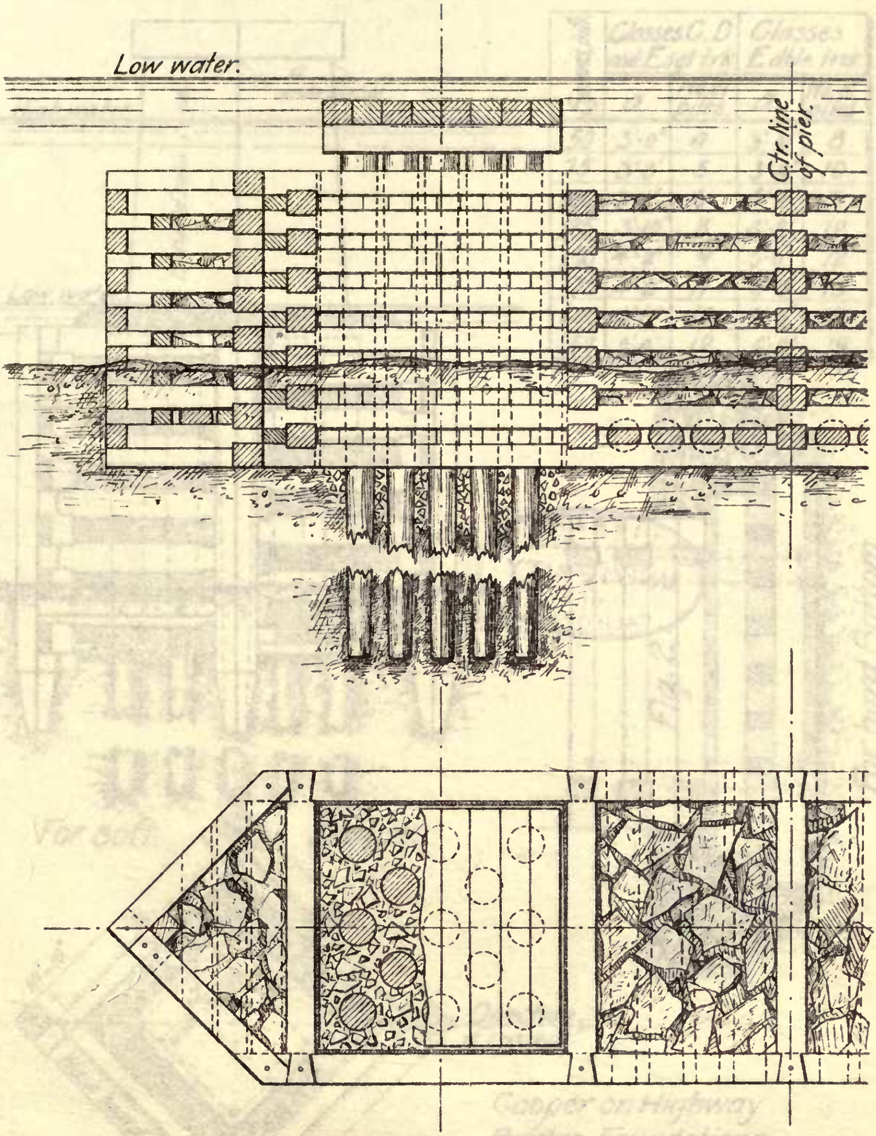


Spans, in feet.	Thickness of pier a: Classes C, D and E sgl. trck.	Thickness of pier a: Classes E double track.
50	2'-10"	3'-4"
75	3'-4"	4'-0"
100	3'-8"	4'-6"
125	4'-0"	4'-10"
150	4'-4"	5'-2"
175	4'-8"	5'-6"
200	5'-0"	5'-10"
250	5'-6"	6'-4"

Cooper on Highway Bridge Foundations.

Plate No. 8.

OBLONG STEEL SHELL PIER.



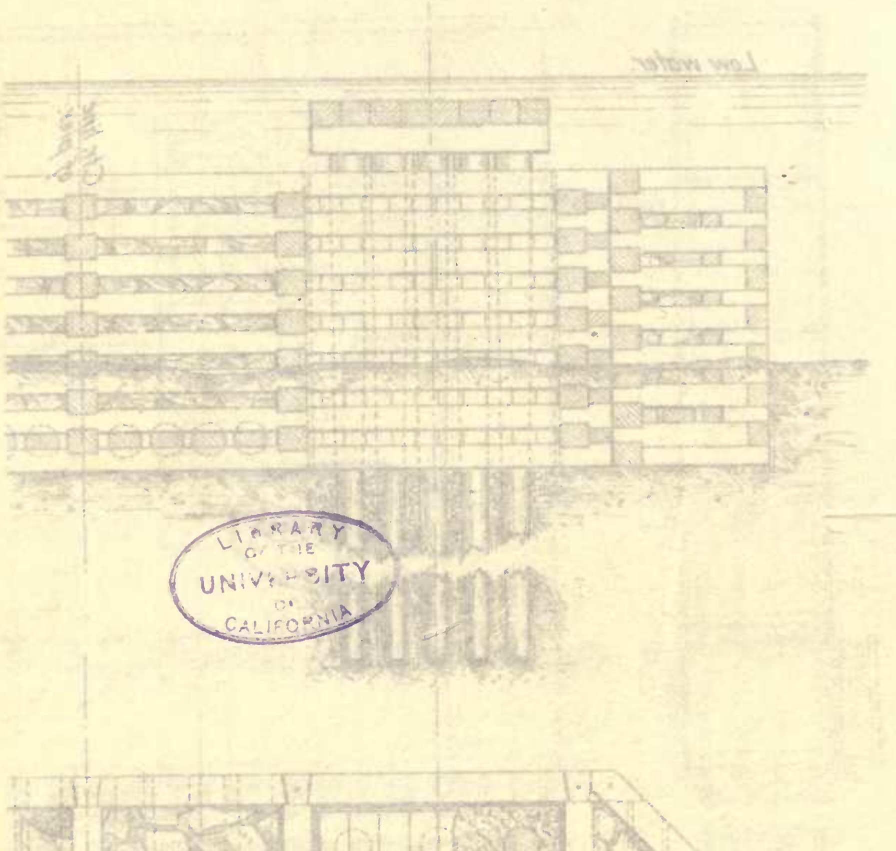
Cooper on Highway Bridge Foundations.

Plate No. 9.

CRIB AND PILE FOUNDATION

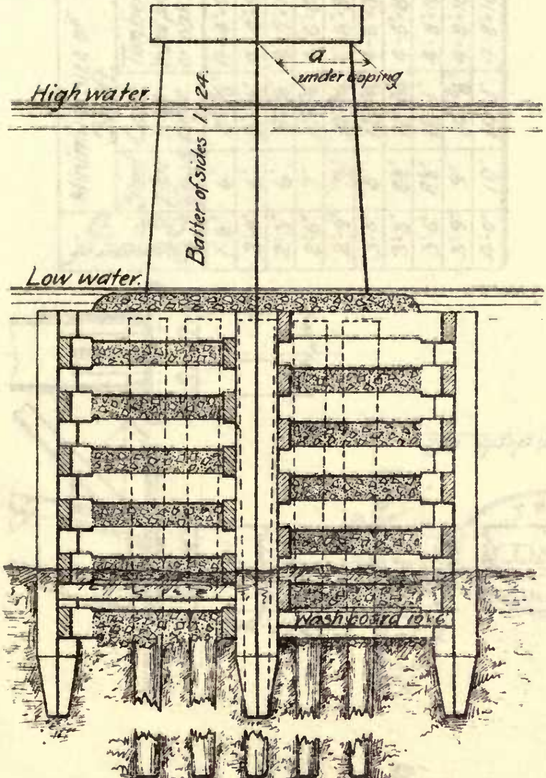
FOR MASONRY OR CYLINDER

PIERS.



Cooper on Highway Bridge Foundations.
Plate No. 9.
CRIB AND PILE FOUNDATION
FOR MASONRY OR CYLINDER
PIERS.

Spans, in ft.	Classes C, D and E sgl. trk. a.	No. of piles.	Classes E dble. trck. a.	No. of piles.
50	3'-0"	4	3'-4"	8
75	3'-3"	5	3'-10"	10
100	3'-6"	6	4'-4"	10
125	3'-10"	8	4'-8"	12
150	4'-2"	9	5'-0"	12
175	4'-6"	11	5'-3"	15
200	4'-8"	10	5'-6"	15
250	5'-4"	12	6'-2"	19



For soft Bottom.

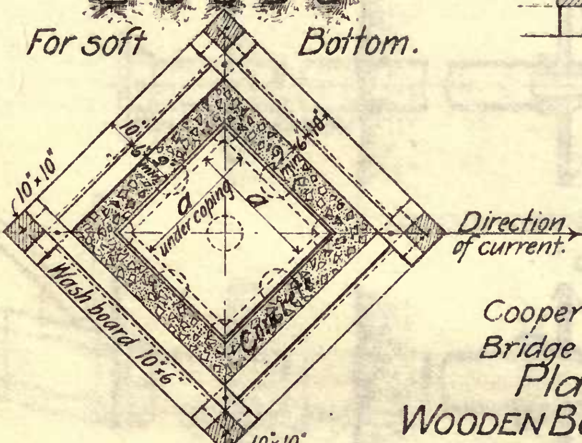


Fig. 1.

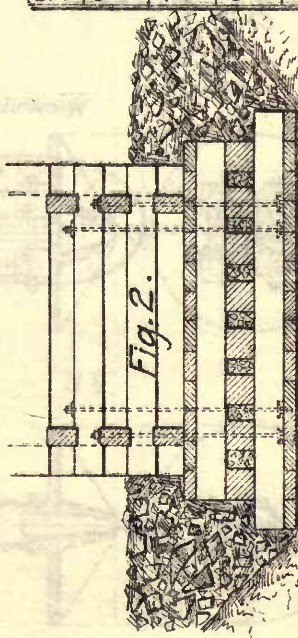


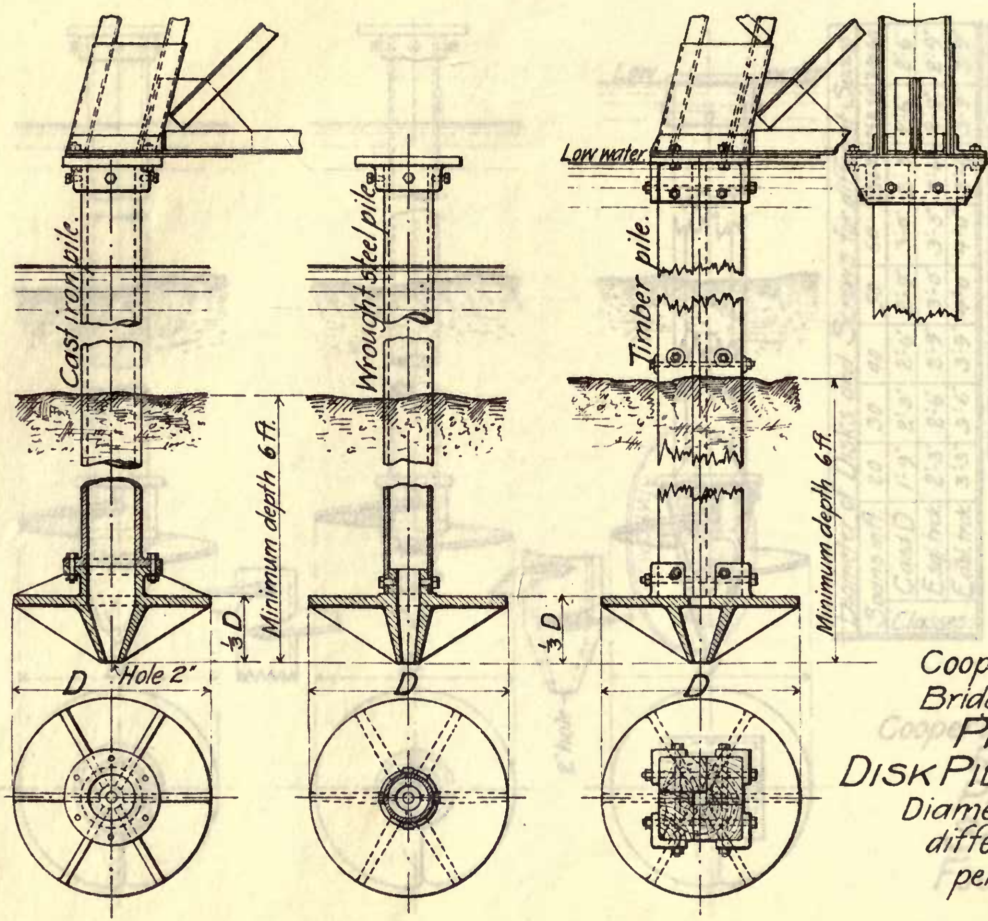
Fig. 2.

For hard Bottom.

Cooper on Highway Bridge Foundations.

Plate No. 10.

WOODEN BOX FOUNDATION FOR MASONRY PIER.



Diameter of Disk "D"	Minimum size of Shaft.		
	Steel pipe ½" thick	Cast iron pipe.	Timber, Yellow pine or oak.
1'-9"	6"	8"×⅝"	4-4"×6"
2'-0"	6"	9"×⅝"	4-4"×6"
2'-3"	6"	9"×¾"	4-5"×7"
2'-6"	7"	10"×¾"	4-6"×8"
2'-9"	7½"	10"×¾"	4-6"×8"
3'-0"	8"	12"×¾"	4-6"×8"
3'-3"	8½"	12"×¾"	4-6"×8"
3'-6"	8½"	12"×1"	4-8"×10"
3'-9"	9"	14"×⅞"	4-8"×10"
4'-0"	10"	14"×1"	4-8"×10"

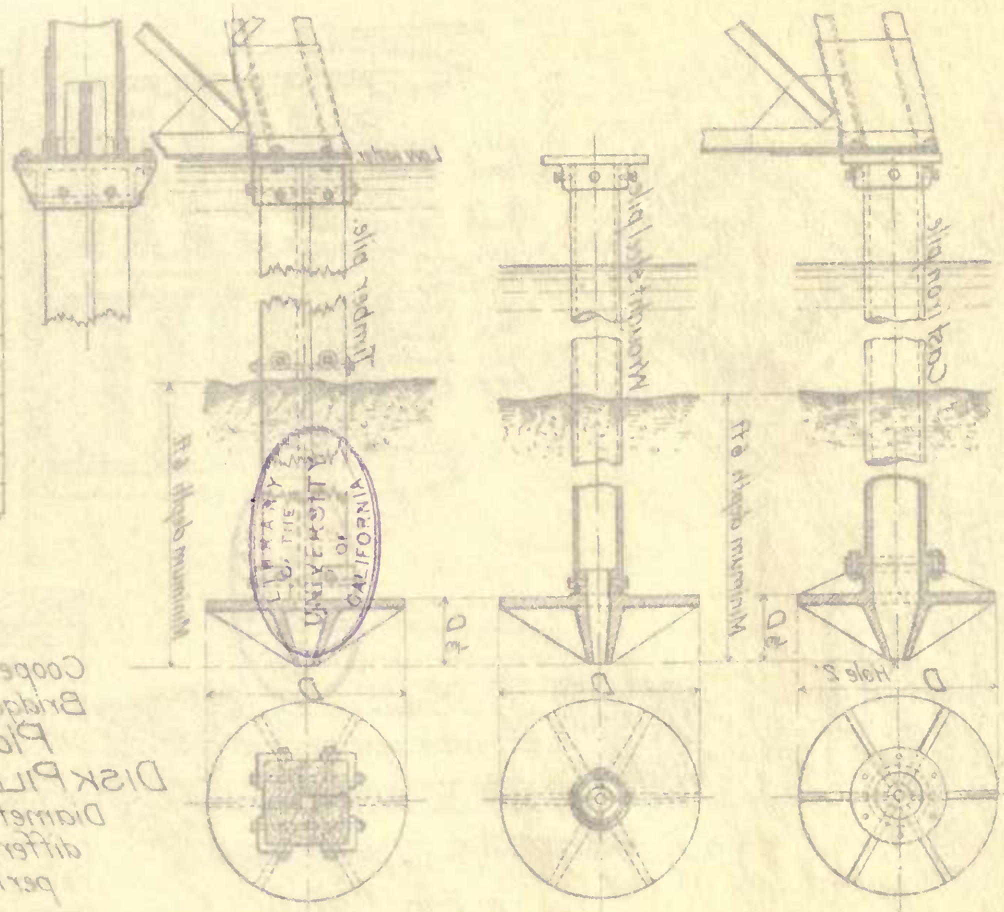
Cooper on Highway Bridge Foundations.

Plate No. 11.

DISK PILE FOUNDATIONS.

Diameter of Disks for different Spans as per Plate No. 12.

Diameter of Disk D.	Minimum size of Shaft. Steel pipe 3/8" thick	Cast iron pipe.	Timber. Yellow pine or oak.
1'-9"	6"	8"×3/8"	4-4"×6"
2'-0"	6"	9"×5/8"	4-4"×6"
2'-3"	6"	9"×5/8"	4-5"×7"
2'-6"	7"	10"×3/4"	4-6"×8"
2'-9"	7½"	10"×3/4"	4-6"×8"
3'-0"	8"	12"×3/4"	4-6"×8"
3'-3"	8½"	12"×3/4"	4-6"×8"
3'-6"	8½"	12"×1"	4-8"×10"
3'-9"	9"	14"×7/8"	4-8"×10"
4'-0"	10"	14"×1"	4-8"×10"

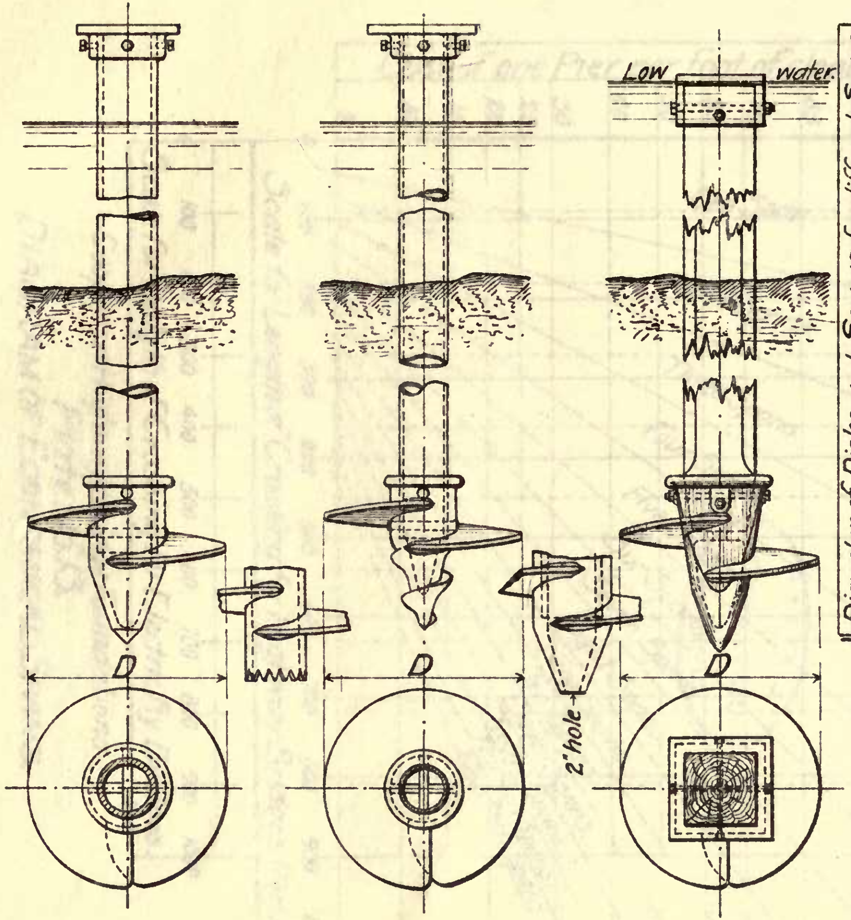


Cooper on Highway Bridge Foundations.

Plate No. 11.

DISK PILE FOUNDATIONS.

Diameter of Disks for different Spans as per Plate No. 12.



Diameter of Disks and Screws for different Spans.

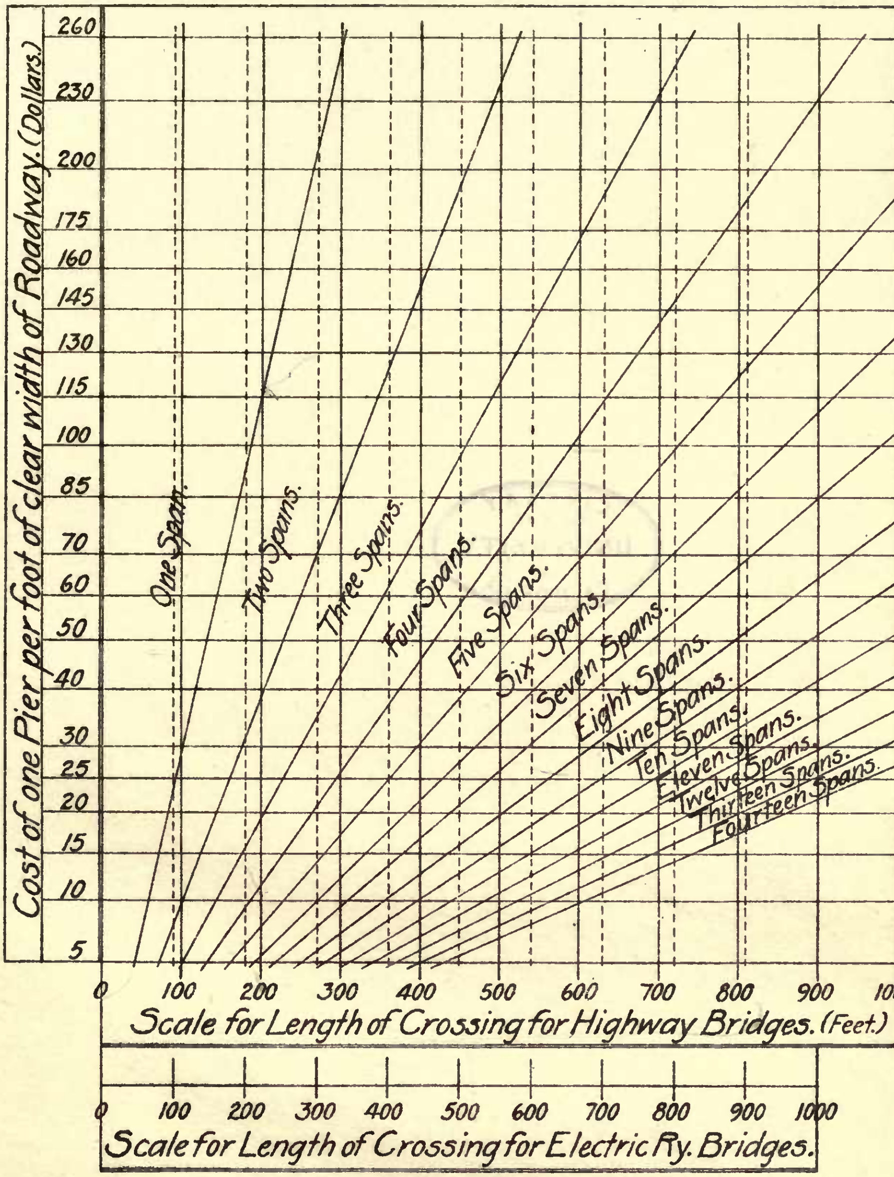
Classes:								
Spans in ft.	20	30	40	50	60	20&40	25&50	30&60
C and D	1'-9"	2'-3"	2'-6"	2'-9"	3'-0"	2'-3"	2'-6"	2'-6"
E sgl. trck.	2'-3"	2'-6"	2'-9"	3'-0"	3'-3"	2'-6"	2'-9"	2'-9"
E dbl. trck.	3'-3"	3'-6"	3'-9"	4'-0"	4'-0"	3'-6"	3'-9"	3'-9"

Diameter of Screw "D".	Minimum size of Shaft.		
	Steel pipe, ½" thick	Cast iron pipe.	Timber, yellow pine or oak.
1'-9"	6"	8"×5/8"	10"×10"
2'-0"	6"	9"×5/8"	10"×10"
2'-3"	6"	9"×3/4"	10"×10"
2'-6"	7"	10"×3/4"	12"×12"
2'-9"	7½"	10"×3/4"	12"×12"
3'-0"	8"	12"×3/4"	
3'-3"	8½"	12"×3/4"	
3'-6"	8½"	12"×1"	
3'-9"	9"	14"×7/8"	
4'-0"	10"	14"×1"	

Cooper on Highway Bridge Foundations.

Plate No. 12.

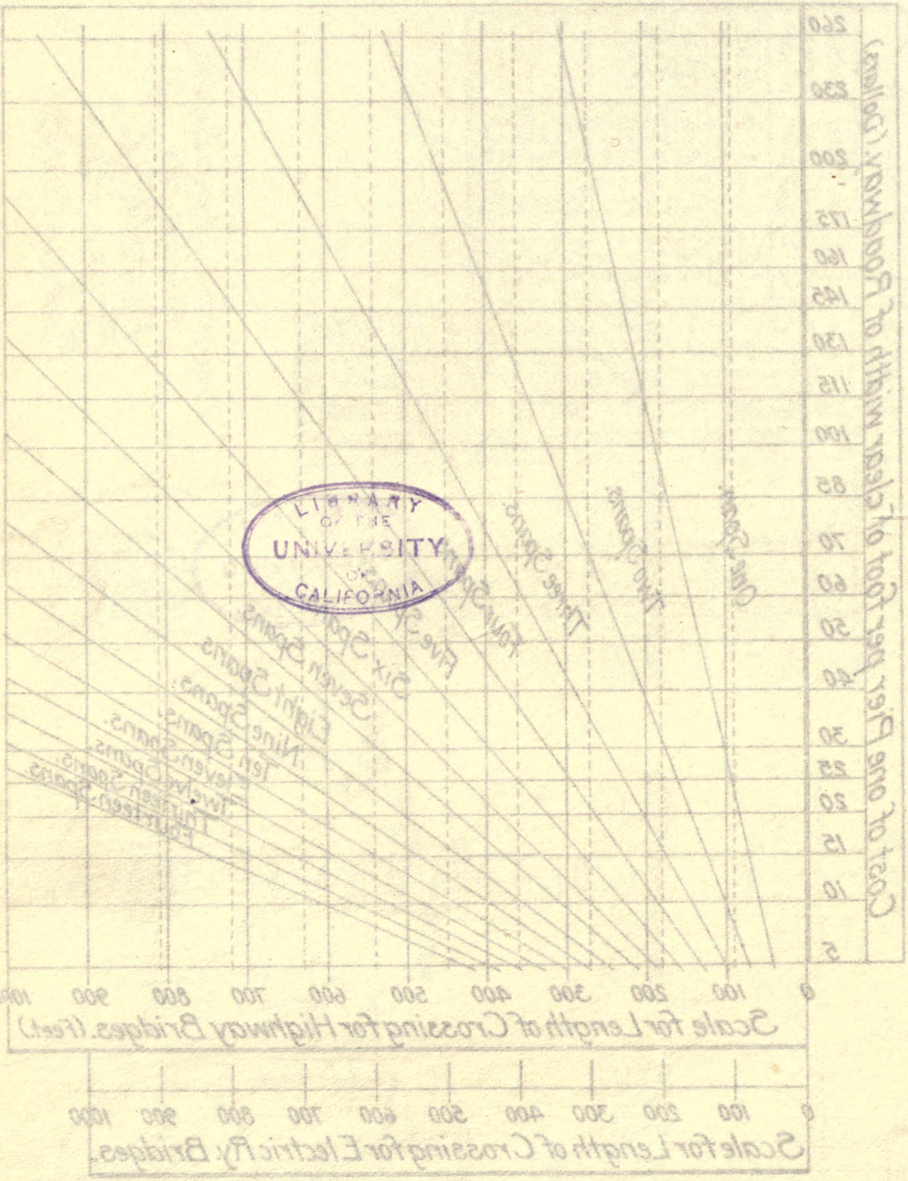
SCREW PILE FOUNDATIONS.



Cooper on Highway Bridge Foundations.

Plate No. 13.

DIAGRAM OF ECONOMICAL SPANS.



Cooper on Highway Bridge Foundations.

Plate No. 13.

DIAGRAM OF ECONOMICAL SPANS.