CORRUGATED METAL SECTIONS — TESTS AND PROPOSED SPECIFICATIONS

(A Report on the Load Deflection Tests on Corrugated Metal Sections conducted by the Michigan State Highway Department and the proposed changes in AASHO 1949 Specifications on Corrugated Metal Sections.)

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First, gentlemen, I would like to briefly point out a few facts from the history of corrugated metal so that we may easier see where the present discussion fits into the picture.

Corrugated metal pipe has been used in the construction of culverts and other underground conduits since 1896. At first, it's use was confined to the smaller waterways with the size of pipe rarely exceeding 36 in. in diameter and generally under small fill heights. These pipes were factory assembled and had corrugations 1⁄2 in. deep and 2 1⁄2 in. wide. In 1931 the industry developed corrugated metal pipe to be assembled in the field from thicker individual plates having corrugations of 1 1⁄2 in. deep and 6 in. wide. This immediately made feasible the use of larger diameters and their placement under higher fills.

No successful rational means of designing this type structure was made for many years—the size of pipe and depth of fill being determined by actual loading tests in a great number of cases. Many agencies have now conducted research on corrugated metal but most of the published work has been on the 1 1⁄2 in. x 6 in. section.

In recent years, 1 3⁄4 in. and 2 in. deep corrugations have been manufactured and considerable discussion has developed concerning the relative merits of the different sections. Also, there has been some disagreement on the correct method of design to be used for the flexible metal structures.

In 1948, the Bridge Committee of the AASHO proposed a comprehensive investigation of corrugated metal plates and structures for the purpose of assisting in the development of a rational basis for the design of structures using the newer sections. This investigation was proposed in two sections; (1) laboratory load tests on various sizes, shapes, and gages of corrugated plate sections, and (2) field investigations on flexible structures under different load conditions.
This report will be divided into two parts: (1) a rather brief description of the laboratory tests conducted by the Michigan State Highway Department Research Laboratory in cooperation with the Bureau of Public Roads; the Armco Drainage and Metal Products Co., Inc.; the Republic Steel Corporation; and the United Steel Fabricators, Inc., and (2) the proposed revisions of the AASHO Specifications as a direct result of the above tests.

The three problems for which solutions were sought thru the investigations were:

(1) Are cross-sectional area and section modulus sufficient information upon which to compute the strength of corrugated metal under bending and direct stress?
(2) Can the experience in the use of the old style 1½ in. corrugation be used for the design of 1¾ and 2 in. corrugation depths with the proper allowance for the increased section modulus?
(3) Do the methods of joining the plates fully develop the strength of the plates in bending and thrust?

The specific laboratory program was organized with the following aims in mind:

(1) To study the influence of size and shape of corrugation on the plate deflections due to loads.
(2) To observe the effect of metal thickness upon plate deflections.
(3) To compare the efficiency of single-bolted and double-bolted fastenings.
(4) To observe the performance of butt joints versus lap joints.
(5) To investigate the effect of bolt torque on joint action.
(6) To measure the stresses in the bolts at plate failure.
(7) To study the influence of plate curvature upon the magnitude of the extreme fiber stress.

The specimens for the tests were obtained from various manufacturers and were of four different thicknesses. Details are shown in Figure 1.

The laboratory tests were divided into six tests, three of which were to measure horizontal and vertical deflections under column loading, one to measure joint slippage in a column, and two to give horizontal and vertical deformations on the sections acting as beams. Diagrams of these tests are shown in Figure 2.
DETAILS OF PLATES AND JOINTS

Fig. 1
The Six Fundamental Tests

Fig. 2
Test 1 was a straight compression column of a specimen $52\frac{3}{4}$ in. long that had no seam or joint and no curvature. The purpose of the test was to observe the type of failure and record the strength of straight metal sheets when subjected to column loading. Figure 3 shows the machine, capable of exerting a 150-ton load thru a hydraulic jack, especially designed for these tests. It consisted of two H columns joined with a movable member at the bottom. The specimen being tested was free to rotate at both ends of the plate in the direction of the least horizontal dimension of the plate thru the use of large loading heads clamped on top and bottom of the column and having a 1 in. round member free to rotate in a circular grooved plate, fastened to the top of the loading head. The load being applied was measured by two dials while the horizontal deflection at the center of the plate was measured by two more.

Test 2 was made on short columns made up of two 24 in. long straight sections bolted together. The test was designed to measure the slippage between the plates and to determine the strength of the seam in shear. Approximately one-half of the specimens were tested on the machine used in Test 1 while the remainder were tested on a 75-ton Riehle testing machine, shown in Figure 4.

The plates rested on a flat plate and the load was applied at the top through a loading head. As shown in the figure, four dials were used to measure slippage between the plates in thousandths of an inch.

Tests 3 and 4 were column tests on both plain and bolted curved specimens with the tests varying only with the curvature of the plates. Test 3 was made on specimens formed to a radius of 150 in. as compared to a 30 in. radius in Test 4. The purpose of both of these tests was to measure the deformation, the resistance to load, and the extent to which the seam developed the full strength of the plates. Figure 5 shows a specimen ready for testing in a frame made up of I-beams and channels. Load transfer devices insured freedom from restraint on the ends when the load was applied with a 50-ton hydraulic jack on the specimens set on edge with the chord vertical. The horizontal and vertical deflections were measured with pairs of dials.
Tests 5 and 6 were made on specimens similar to those in tests 3 and 4 and were simple beam tests. The specimens of test 5 were formed to a radius of 150 in. and those of Test 6 to a radius of 50 in. with both plain and bolted specimens being used. The purpose of these two tests was to measure the horizontal and vertical displacements of the plates, the characteristics of the failed section, and the efficiency of the joint while the plate was acting as a beam. One specimen ready for testing, is shown in Figure 6.

Care was taken to insure freedom from horizontal constraints on the ends which were supported on two concrete block piers capped with a steel plate. A two point loading was used to transfer the load to the plates as the joint fasteners on the bolted sections interfered with a single load arrangement. The plain plates were similarly loaded for uniformity. Vertical deflection was measured with two dials while the horizontal changes in span were measured with a straight edge.

The test procedure in all the tests was essentially the same with the application of the load continuing through the yield point until a maximum value was reached after which succeeding deformations resulted from loads less than this ultimate figure. On the bolted specimens a torque wrench was used to tighten the bolts with a torque of 200 ft. lb. Strains in various parts of the specimens were measured with a Baldwin Southwark indicator. Load increments varied with the requirements of the tests and in all cases were determined by the number of values needed to plot a smooth curve of the results. Among the special tests made other than the above were strains on the outer fibers, tensile stresses on bolts, apparent strength of some of the bolts used in the joints, and study of the characteristics of the metal was made.

The results of the series of tests were used to construct graphs for easier comparison of the influence of the various factors upon plate performance. Examples of these are shown in Figure 7, from Test 3, and in Figure 8 from Test 5.

Examples of typical failures are shown in Figure 9, from Test 3; Figure 10 from Tests 5 and 6, and in Figure 11.
TEST 5

TYPICAL FAILURES, PLAIN & BOLTED, TYPE R

TEST 6

Fig. No. 10
TYPICAL FAILURES AT JOINTS

Fig. No. 11
CONCLUSIONS

1. Extreme fiber stresses at approximately the elastic limit were computed from the observed strains and compared quite favorably with the stresses computed from the section modulus of the specimens. Therefore, it was concluded that corrugated metal sections may be designed on the basis of section modulus for 1 ½, 1 ¾, and 2 in. depths for the circular arc type corrugation and for 2 in. depth for the box type corrugation.

2. The ultimate strength of the No. 12 gage specimens was below that of the No. 1, 7, and 10 gage specimens, so it may be that under ultimate stress the thin gage metal, No. 12, deforms to such an extent that the section modulus is not entirely effective.

3. The standard lap joint nearly develops the ultimate strength of the corrugated metal but slippages and yielding take place which lowered the elastic limit. Double bolting increases the lowered elastic limit and reduces the tension bolt stress.

4. The butt joint developed full strength of the section under pure compression but is less efficient in bending than the lap joint.

5. A reasonable value of bolt torque to be used in practice appears to be 200 ft. lbs.

PROPOSED REVISIONS TO THE AASHO 1949 SPECIFICATIONS

The AASHO subcommittee on Corrugated Metal has rewritten the portions of Divisions II, III, and IV of the 1949 AASHO Specifications pertaining to Sectional Plate Pipe and Arches incorporating the results of the Michigan State Highway Department investigation. The work of this committee under the heading ‘Structural Plate Pipe, Arches, and Pipe-Arches’ is now being reviewed by the Bridge Committee of the AASHO in preparation for balloting in the near future. I have attempted to include in the following the highlights of the proposed revisions.

Perhaps the principal feature is that the depth of corrugation has been changed from a minimum of 1½” to a standard 2” with a minimum radius of 1 1/16” on the inside of the corrugation. This, if adopted, will have the effect of standardization within the industry—certainly a tremendously step forward. It is my understanding that the various manufacturers, anticipating approval by the AASHO, are now making this change in their mills.

The second main feature, and one at present still in the controversial stage, is the inclusion of No. 12 gage in the various gage tables for Structural Plate Pipe and Pipe-Arches.

A third major change is that ¾” round instead of 11/16” round
bolts have been specified to match the added strength of the corrugations.

Other proposed changes include the following:—
1. Pipe-Arches have been included for the first time.
2. The maximum weight per plate has been set at 750 lbs. with plates available to allow structure length increments of 2 ft. instead of 2½ ft.
3. Rewording the specifications to call for unstrutted pipe unless otherwise called for on the plans.
4. Allowing omission of the channel or angle metal bearing surface for arch spans of 15 ft. or less and for those having a skew angle of 20° or less.
5. The minimum height of cover is at present a minimum of 2 ft. from finished grade to top of pipe. This has been changed to a minimum for pipes of the ratio of the diameter of the pipe to 5 or 7 (depending on the pipe size) and for pipe-arches to the ratio of span to 10 or 14. So for less than 10 ft. diameter pipe the minimum fill depth has been decreased and for over 10 ft. diameter increased under unpaved and flexible pavements.
6. The present specifications makes the bottom plates a thicker gage than the top ones. This has been revised to allow pipe gages to be uniform throughout unless the thicker gage is required on the bottom due to special field conditions.
7. When the skew angle exceeds 20 degrees and the pipe or pipe-arch has the ends cut to fit the slope, the ends shall be reinforced with masonry.
8. In Structural Plate Arches all gages have been reduced for all spans under the fills shown.
9. The minimum height of cover for arches in the present specifications is 2 ft. minimum for earth alone, 18 in. minimum under flexible type pavements, and 6 in. minimum under rigid type pavements. This has been changed to have a cover of S/15 with a minimum of 12 in. under unpaved and flexible pavements and S/20 with a minimum of 6 in. under rigid pavements.
10. While no change has been made in the chemical requirements of the base metal or process, the 3 ounce spelter coating now required on pipe of 135-160 in. in diameter has been omitted thus calling for only a 2 ounce coating on all corrugated metal. This change allows fabrication after galvanizing which can be done with no damage to the coating.
11. A change has been made in the method of gage determination. Gages will be determined by the weight of fabricated galvanized plates instead of present weight of flat plates before galvanizing.