

Review of Specifications for Buried Corrugated Metal Conduit Installations

ERNEST T. SELIG

ABSTRACT

The national specifications for AASHTO and the American Iron and Steel Institute for buried corrugated metal conduits for the past 15 years are reviewed. Increasing restrictions on backfill conditions are shown and limitations of the backfill specifications are pointed out. Deficiencies in compaction specifications are indicated. Changes in deflection guidelines are described, including the undesirable elimination of tolerances for ordinary conduits. Implications in the trends for the allowable flexibility factor are considered. The need for clarifying the functions of the special features on the long-span structures is indicated. Some aspects of conduit design needing further research are suggested. The establishment of a unified set of specifications incorporating both ordinary and long-span conduits is suggested. Finally, a reexamination of existing culverts built under previous, less restrictive guidelines is recommended.

The design and installation requirements for buried corrugated metal conduits, including structural plate pipe, pipe-arches, and arches, have continued to evolve over the years on the basis of experience and, to some extent, research. The maximum size has increased to the point that a new category, known as long span, has been established. An examination of past national specifications gives insight into this experience and shows some of the deficiencies in practice.

The history of the American Association of State Highway and Transportation Officials (AASHTO) and American Iron and Steel Institute (AISI) culvert specifications during the past 15 years is reviewed. Emphasis is on the larger sizes of conduits constructed of structural plate, which are the most critical from the standpoint of public safety. The specifications are evaluated and areas for further study are suggested.

ARMCO HANDBOOK

In 1958 Armco, Inc., published the Handbook of Drainage and Construction Products (1), which became the source of much of the information on design and installation of buried corrugated metal structures for subsequent standards. The Armco handbook gives representative sizes of multiplate corrugated metal structures. The largest is a semicircular arch (1, pp.90-92) with a 30-ft span and 15-ft 1-in. rise. A table of soil characteristics (1, pp.302-303) indicates the following:

1. Gravelly and sandy soils may be used for embankments,
2. Inorganic low-plasticity silts and clays (liquid limit less than 50) have poor stability but may be used for embankments with proper control,
3. Inorganic high-plasticity silts and clays (liquid limit greater than 50) are not desirable in rolled fill construction,
4. Organic silts and clays are not suitable for embankments, and
5. Highly organic soils are not used for construction.

More specifically, the Armco handbook indicates (1, p.446) that the backfill around corrugated metal structures should be good material, properly placed and carefully compacted. Selected, drainable backfill material is preferred, but most local fill material can be used provided it is carefully placed and compacted. It should be free from large rocks and lumps or clods larger than 3 in. in diameter. Frozen fill, sod, cinders, or earth containing a high percentage of organic material should not be used. Granular material containing a small amount of fill or clay is ideal. The fill should be placed alternatively in 6-in. layers on both sides of the pipe to permit thorough tamping. The fill should be maintained at about the same elevation on both sides of the structure at all times.

AISI HANDBOOK

The AISI handbook dealing with culverts was first published in 1967 (2); the second edition was published in 1971 (3) and the third edition in 1983 (4). Extensive use is made of material from the Armco handbook. In fact, in the 1967 AISI handbook it is acknowledged that the Armco handbook was a precursor.

The 1967 edition (2, p.22) and the 1971 edition (3, p.38) list representative sizes and shapes of structural plate corrugated metal conduits. The shapes given are round, vertical ellipse, pipe-arch, underpass, and arch. The largest size listed is a semicircular arch of 25-ft span with a 12-ft 6-in. rise.

In the discussion of structural design in the 1971 handbook, a value of 85 percent compaction is recommended based on the AASHTO T-99 (ASTM D698) standard test method for routine design, considering that most specifications will call for 90 percent. The 1967 handbook does not give compaction levels.

The structural design involving wall crushing, wall buckling, and seam strength is based on ring compression thrust (T), which is calculated as

$$T = K(\gamma h + LL)(S/2) \quad (1)$$

where

T = thrust (lb/ft),
 γ = soil unit weight (lb/ft³),
 h = height of cover over crown (ft),
 LL = live-load pressure (lb/ft²),
 S = span (ft), and
 K = load factor.

In 1967, $K = 1$ and $\lambda = 100$ lb/ft³. In 1971 (3,p.89), the load factor varied from 0.86 for 85 percent compaction (AASHTO T-99) to about 0.65 for 95 percent compaction. However, when the height of cover is less than the pipe diameter, K is taken as unity. When the height of cover exceeds the diameter, a value of $K = 1$ corresponds to 80 percent standard compaction.

This method not only neglects the weight of soil over the culvert between the crown and springline but also assumes positive arching in terms of thrust for height of cover greater than the diameter. For large structures at least, negative arching for thrust has been observed even considering the soil weight below the crown.

In 1971 a factor of safety of 2 is specified for yield and buckling stress. In 1967 no factor of safety is specified, but sample calculations indicate a factor of safety of 2. In 1971 the design thrust load is specified to be at most half the ultimate seam strength, thus giving a factor of safety of 2 against seam failure. In 1967 no factor of safety is specified, but sample calculations indicate a factor of safety of 4.

Handling stiffness is defined by a flexibility factor (FF). The maximum value in both 1967 and 1971 is 0.02 in./lb for pipe with bolted seams and 6- x 2-in. corrugations. In the 1971 handbook it is stated that higher values may be used with special care. Aluminum pipe is cited as an example. Because aluminum has a lower modulus than steel, aluminum conduits have been allowed a higher FF. However, no theoretical reason for this distinction has been reported. Thus in the 1971 AISI handbook it is pointed out that when this higher flexibility is acceptable for aluminum, it is also acceptable for steel.

In the 1971 AISI handbook it is stated (3,p.93) that deflection is an important consideration in buried conduits. It is stated in part that "if the deflection is a smooth, symmetrical distortion of the conduit wall, a movement of 5% below round is considered structurally sound. A movement of 20% below round will ordinarily result in reversal of curvature." Further it is stated that deflection of the conduit is not ordinarily the criterion for design because "backfill soil compacted to normal minimum practice (\geq 85% standard AASHTO density) is more than enough to allow the conduit to carry load in ring compression up to its full strength in crushing or buckling without deflection distress." In 1967 it is recommended (2,p.51) that periodic inspection of any culverts with greater than 10 percent deflection be made to see that they have stabilized.

The high corner pressure applied to the backfill by a pipe-arch shape is discussed in the 1971 handbook (3,p.95) as a limiting factor in the design of such structures. According to this handbook (3, p.96), the semicircular (or less than semicircular) arch is the most restrictive shape. Only the use of very high safety factors is said to have made this common arch shape practical. The recommended design factor of safety for arches that are semicircular (or less) is twice that for round pipe. Although in the 1971 handbook it is unclear to which design consideration this relates, apparently wall yield stress, buckling, and seam strength were intended.

For H-20 live load on structural plate structures with 6- x 2-in. corrugations, the height-of-cover limit tables in 1967, which are only for round structures, give 21 ft as the largest span with a maximum cover height of 34 ft. In 1971 the tables list 26 ft as the largest span, which is for both round and arch shapes. This size is shown only with 1-gauge thickness (0.028 in.). The maximum height of cover for the round structure is 35 ft and for the arch, 18 ft.

In the 1971 earth backfill design section (3, p.126), it is stated that stability of a soil-structure interaction system requires not only adequate design of the structural barrel but also a well-engineered fill. Performance is said to depend greatly on selection, placement, and compaction of the envelope of earth surrounding the structure and distributing its pressures to the abutting soil masses. Requirements for selecting and placing backfill material around or near the conduit are said to be similar to those for a roadway embankment. Granular backfill material is recommended to provide good structural performance. Cohesive-type material is also permitted if careful attention is given to compaction at optimum moisture content (3,p.126). Bank-run gravel or similar material compacted to 90 to 95 percent standard density is cited as ideal. Compaction to 85 percent is recommended as a minimum allowable under any circumstances.

Although the 1967 handbook does not give levels of compaction, the wording implies that it should be more than 85 percent, and somewhat greater emphasis is given to compaction than in 1971. In particular in the 1967 handbook (2,p.170) it is stated that "too much emphasis can not be placed on the necessity for adequate compaction of backfill. Faulty compaction has led to more trouble with pipe installations than all other factors combined." These words were not included in 1971.

Brief conduit foundation preparation guidelines are given. This information is repeated and expanded in the chapter on installation. In all editions of the handbook it is stated that reasonable care is required in construction so that proper performance will be achieved.

In the guidelines it is stated that the bedding should be shaped over a wide enough area of the conduit bottom so that the backfill can be compacted under the haunches. A uniform blanket of loose material should cover the shaped bedding to allow the corrugations to become filled with the material. The conduits should not be placed on either very hard ground (like rock) or very soft ground (like muck). Soft ground should be excavated and replaced with granular fill. Hard ground should be excavated and replaced with softer material.

Six pages in the 1971 handbook are devoted to soil backfill (2,pp.246-251). A well-engineered backfill is presumed. The importance of backfill to the performance of the structure is indicated. Requirements for selecting and placing backfill around the conduit, which are similar to those for a roadway embankment, are given. However, it is stated that higher lateral pressures may be generated than those in highway embankments.

In the 1967 and 1971 guidelines it is preferred that backfill material be granular, but cohesive soils can be used if they are properly compacted. In the 1967 handbook the ideal backfill is granular material containing a small amount of silt or clay. In the 1971 handbook bank-run gravel or similar material compacted to 90 to 95 percent standard density is ideal. The minimum recommended compaction level is 85 percent. The fill should be placed in 6-in. layers evenly on both sides of the pipe. Most types of compaction equipment are permitted when

conditions are appropriate. Compaction by puddling or jetting is not recommended. Methods of backfilling to maintain structure shape are described.

In the 1983 AISI handbook (3,p.38) many more shapes are shown than in the 1971 handbook. The newly added shapes are horizontal ellipse, pear, high-profile arch, low-profile arch, and box culvert. The maximum size of the old shapes has not changed from the 1971 handbook except for an increase in the diameter of the round shape from 21 to 26 ft. Except for the box culvert the new shapes are all larger than the old ones. The largest is a low-profile arch shown up to 50 ft in span. These new structures are all in a new long-span category.

The allowable wall stress is unchanged in 1983 from 1971. However, in 1971, when the height of soil cover was less than one pipe diameter, the load factor was increased to $K = 1$. This means that for shallow cover, all the weight of soil above the conduit crown was assumed in 1971 to be carried by the conduit. In 1983 this provision was eliminated, thus decreasing the design load for shallow cover.

The seam-strength criterion is the same in 1983 as in 1971, although it is stated in 1983 (3,p.108) that most seams develop the full yield strength of the pipe wall.

The flexibility factor is increased in 1983 by a factor of 1.3 for arch and 1.5 for pipe-arch structures. The 1971 value of 0.02 in./lb remains the same in 1983 for other conduit shapes.

In 1983 the discussion of deflection has been eliminated. The discussion of pipe-arches is unchanged. The wall yield and buckling factor of safety for arches is increased about 33 percent over that for full-round pipe and then only for less-than-semicircular shapes. Thus arch design has become less conservative than in 1971.

A major change in 1983 is the addition of a new section on long-span structural plate structures. This section is taken directly from the AASHTO specifications and will be discussed later.

The height-of-cover tables in 1983 show the same maximum sizes for the round and arch shapes as in 1971. However, the maximum height of cover for the 26-ft span, 1-gauge arch has increased from 18 to 27 ft and arches of this span are allowed in thinner gauges if the soil-cover heights are less than 26 ft. Long-span structures can be larger, but these largest sizes in the non-long-span tables also should be used with caution if they are not designed and constructed under the long-span guidelines. The reason is that the standard pipe or conduit guidelines are not adequate for such large sizes, especially when intended as bridge structures. The inadequacy is related primarily to the less-restrictive soil conditions but also to less-demanding installation control in the non-long-span category.

In the 1983 chapter on installation, a vee-shaped bedding is given as an alternative to bedding shaped to the conduit bottom. The need for high-quality, highly compacted fill under the corners of pipe arches is indicated. Structural backfill is shown to extend to a width of one diameter or span from the sides of the conduit. More details are given for treatment of soft foundations and for transitions from compressible soils to rock.

In the 1983 handbook it is recommended that backfill be compacted to 90 percent of AASHTO T-99 density. This is a more specific recommendation than that in 1971. Layer thickness may range from 6 to 12 in. Whether this is loose or compacted thickness is not indicated. Mechanical compaction is preferred, but water consolidation may be used when the desired results are achieved. The other guidelines are similar to those in 1971.

The 1983 handbook has a new section on installation and backfill of long-span structures. Granular soils are required for the structural backfill. For full heights of less than 12 ft, AASHTO type A-1, A-3, A-2-4, and A-2-5 may be used. For over 12 ft, only A-1 and A-3 are recommended. The compaction level is a minimum of 90 percent AASHTO T-180 density. The width of the backfill zone is not specified. In practice the width used is much less than the one span recommended for the smaller structures.

Backfill placement for long-span structures must be done in a way that controls shape. The conduit manufacturer is to provide a qualified construction inspector to aid and advise the engineer during all backfilling. Layer thickness should not exceed 8 in. after compaction. Less compaction is required under the invert, adjacent to large-radius side plates, and in the first lift over the structure.

Clearly the long-span backfill requirements are much more severe than those for the other conduits. However, the larger sizes of non-long-span conduits also should follow the long-span guidelines in most applications, particularly when roads or railroads are involved, because the lower compaction standards, the reduced construction controls, and the use of nongranular fill for ordinary conduits permit installed structures with conditions that have resulted in unsatisfactory performance or collapse in the past.

A summary of some of the AISI design factors is given in Table 1.

TABLE 1 Summary of AISI Design Factors for Ordinary Structural Plate Conduits

Factor	1967	1971	1983
Largest span (ft)	25	25	50
Factor of safety			
Wall yield			
Arch	?	4	2.7
Other	2	2	2
Wall buckling			
Arch	?	4	2.7
Other	2	2	2
Seam strength			
Arch	?	4	2.7
Other	4	2	2
Flexibility factor ^a			
Arch	0.02	0.02	0.026
Pipe arch	0.02	0.02	0.03
Other	0.02	0.02	0.02
Span (ft)/cover (ft) ^b			
Round	21/34	26/35	26/35
Arch	-	26/18	26/27

Note: ? = value unknown.

^a Inches per pound for 6- x 2-in. corrugation with steel.

^b From maximum height-of-cover tables.

AASHTO SPECIFICATIONS

The AASHTO (later AASHTO) specifications (5) dealing with corrugated metal and structural plate pipes and pipe-arches build on the experience and concepts presented in the Armco handbook. The structural design portion of these specifications was essentially unchanged for the period 1969-1972. The design criteria for such structures were as follows:

1. Seam strength,
2. Handling and installation strength,
3. Failure of the conduit wall, and
4. Deflection and flattening.

Failure in bending is assumed not to occur in flexible conduits. The flexibility factor ($FF = D^2/EI$) was specified as a maximum of 0.02 in./lb for 6- x

2-in. corrugation steel conduits. Additional values are specified for other steel and aluminum corrugations. A maximum deflection of 5 percent of nominal diameter below circular shape is allowed. The safety factor for pipe wall buckling is 2 and for longitudinal seam strength is 4.

The wall thrust used to check yielding, buckling, and seam strength is determined from a relationship corresponding to Equation 1, but with $K = 1$. In addition, the soil unit weight (λ) is taken as 70 to 100 percent of the actual value, depending on the installation conditions. However, alternative equations are given for the term λh when the culvert is untrenched on unyielding foundation. These equations, based on Marston's theory, result in dead-load pressures greater than λh . The live-load pressure (LL) is determined by

$$LL = F/(3.06h^2) \quad (2)$$

where F is the concentrated surface wheel load in pounds and h is the height of soil cover over the crown in feet. This pressure is then assumed to be distributed uniformly over the entire culvert. These relationships have remained essentially unchanged through 1981.

Structural plate arches were not covered by the foregoing specifications for pipes and pipe-arches in 1969. Instead minimum-gauge tables were provided as a function of arch span, height of cover, and live load (either H15 or H20). The corrugation is not considered. For the H15 load the largest span in the table was 28 ft and this required 1-gauge steel plate with a single height of cover, which was 6 ft. For H20 load the maximum span listed was 25 ft, which was also limited to 1 gauge and 6 ft of cover. The permitted ratios of rise to span were 0.2 to 0.5. However, some restrictions were placed on arches with less than 0.3 rise-span ratio, and a minimum height of cover was specified.

In 1972 significant changes were made by AASHTO for structural plate arches. The design requirements for arches were made the same as those for pipe and pipe-arches. The minimum-gauge tables were eliminated. The rise-span ratio was limited to the range of 0.3 to 0.5. Also the minimum height of cover was changed.

For the period 1969-1972 the construction and installation specifications remained unchanged. These specifications applied to pipes, pipe-arches, and arches.

According to AASHTO specifications in 1969 (5,p.319):

Sidefill material within one pipe diameter and not less than one foot over the pipe shall be fine, readily compactible soil or granular fill material. Sidefill beyond these limits may be regular embankment fill. Job-excavated soil used as backfill shall not contain stones retained on a 3-in. ring, frozen lumps, chunks of highly plastic clay, or other objectionable material. ... Sidefill material shall be placed as shown in [AASHTO] Figure 2.23D [p.321], in layers not exceeding 6 in. in compacted thickness at near optimum moisture content by engineer-approved equipment to the density required for superimposed embankment fill. ... The sidefill...shall be brought up evenly and simultaneously on both sides of the pipe to not less than 1 foot above the top for the full length of the pipe. Fill above this elevation may be material for embankment fill.

AASHTO Figure 2.23D (5,p.321) contradicts the requirement (5,p.319) for the sidefill to cover the zone within one pipe diameter from the sides. The figure shows the width of the sidefill to be 2D minimum ($D =$ pipe diameter) and 12 ft maximum. This is an impossible set of constraints for a pipe greater than 6 ft in diameter.

In 1976, AASHTO (formerly AASHTO) reduced the factor of safety for seam strength to 3 based on more recent research. The specifications were also revised in 1976 to emphasize the undesirability of a rigid foundation for a flexible culvert. Also, it was pointed out that the footing reactions for the metal arch are considered to act tangentially to the metal plate at its point of connection to the footing.

In a new section on assembly in 1976 (5,p.25), the AASHTO specifications indicate that backfill including fine sands and silts can be a problem because it is erodible and hence subject to piping action at the joints. It is implied that soils such as coarse sand, gravel, and cohesive clays may be used as backfill next to the pipe. Also large soft spots, voids, and organic silt are considered poor soil conditions. These can be tolerated only for relatively low fill heights and necessitate more stringent requirements on transverse joints.

In 1977 the maximum allowable flexibility factor for 6- x 2-in. corrugation pipe-arch was increased to 0.03 in./lb. The flexibility factor for 6- x 2-in. corrugation pipes remained 0.02 in./lb. These specifications make ambiguous which value pertains to 6- x 2-in. corrugation arches. This ambiguity was not corrected until 1981.

Also in 1977, AASHTO first introduced a major new set of specifications for long-span structural plate structures (5,p.248). Long-span structures are defined as those that exceed the maximum sizes imposed by the flexibility factor or have a relatively large radius of curvature. Such structures are allowed to be exempt from the limits on flexibility factor as well as the wall-buckling and crushing requirements if certain special features are added: longitudinal stiffeners, soil bins, or ribs. For design, the wall thrust is determined from Equation 1 with twice the top arc radius rather than the span. Except perhaps for a vertically elongated ellipse, this will give a wall thrust greater than that based on the span as assumed for non-long-span culverts. Furthermore, the previous deflection criteria are not applicable. Instead construction procedures must be used such that severe (not defined quantitatively by AASHTO) deflections do not occur during construction.

For long-span structures a minimum thickness of the top arc plates is specified that is a function of the top radius. There is also a minimum soil-cover thickness, which is a function of the top radius and plate thickness. Finally geometric limits are specified relating to the plate radii. Structures that do not meet these requirements are designated as special designs. Two examples of structures requiring special design are a semicircular arch and a round shape. These both have a ratio of top arc radius to side arc radius of 1.0, whereas the geometric limits specify a minimum ratio of 2.0. No guide is given for these special designs, however.

In addition, the AASHTO soil requirements for long-span structures (5,p.248) are significantly different from those for ordinary conduits. In the long-span specifications it is stated (p.37) that granular-type soils must be used as structure backfill (the envelope next to the structure). The order of preference of acceptable structure backfill materials is as follows:

1. Well-graded sand and gravel, rough or angular if possible;

2. Uniform sand or gravel; and
3. Approved stabilized soil under direct supervision of a competent experienced soils engineer.

Plastic soils are not to be used. For heights of fill less than 12 ft, the acceptable soils are (p.39) AASHTO A-1, A-3, A-2-4, and A-2-5. For fill heights greater than 12 ft only soils A-1 and A-3 are permitted. This backfill is to be placed and compacted to not less than 90 percent AASHTO T-180 (modified compaction) density.

The soil envelope about the barrel is required to be extensive enough to prevent shearing planes from developing in the envelope (p.249). To each side of the barrel, the soil envelope or sidefill is to extend a minimum horizontal distance of half the span or two-thirds of the total rise, whichever is greater. It is not necessary to excavate native soil at the sides if the quality of the native soil is already as good as the proposed compacted sidefill. The soil over the top is also to be select and carefully and densely compacted.

In a section on assembly of long-span structures, it is stated (5,p.433) that the distortion of the structure before backfill is not to exceed 2 percent of the span or rise, whichever is greater, but is in no case to exceed 5 in. The previous sidefill requirements for pipe, pipe-arch, and arches with footings still contain the contradictions pointed out in the 1977 specifications. However, a new section on backfill for long-span structures has been added (pp.435-436). In this new section it is stated that, although the basic backfill requirements for long-span structures are similar to those for smaller structures, their size is such that excellent control of placement and compaction must be maintained. Because these structures are especially designed to fully mobilize soil-structure interaction, a large portion of their full strength is not realized until backfill (sidefill and overfill) is in place. Of particular importance is control of structure shape. Equipment and construction procedures are to be used so that excessive structure distortion will not occur. Structure shape is to be checked regularly during backfilling to verify acceptability of the construction methods used.

Magnitude of allowable shape changes will be specified by the manufacturer (fabricator of long-span structures). The manufacturer is to provide a qualified construction inspector to aid the engineer during all structure backfilling. The inspector will advise the engineer on the acceptability of all backfill materials and methods and the proper monitoring of the shape. Structure backfill material is to be placed in horizontal uniform layers not more than 8 in. thick after compaction and is to be brought up uniformly on both sides of the structure. Each layer is to be compacted to a density not less than 90 percent AASHTO T-180. Permissible exceptions to required structure backfill density are under the invert, adjacent to large radius side plates, and the lower part of the first lift over the structure.

The 1978 interim specifications for corrugated pipe clarified that the factor of safety of 2 for buckling also applied to wall yield strength.

In 1981 further important changes were made in the AASHTO specifications. In Section 9, which covers conduits of both long-span and non-long-span type, the deflection or flattening criterion has been eliminated from the design evaluation. This was not because deflection is considered an unimportant factor for flexible culverts, but rather that deflection is controlled by soil properties and method of installation. The sections on soil design and on construction and installation have been modified accordingly. These changes primarily affect the non-long-span structures because they had been con-

sidered when specifications for long-span structures were introduced in 1977.

In the new 1981 specifications for all conduits, the minimum width of soil envelope was 2 ft on each side of the culvert for trench installations and one diameter or span each side of the culvert for embankment installations. The minimum upper limit of soil envelope is 1 ft above the culvert. Good sidefill is stated to be a granular material with little or no plasticity and free of organic material, that is, AASHTO classification groups A-1, A-2, and A-3, and compacted to a minimum of 90 percent of standard density (AASHTO T-99 or ASTM D698). Specific compaction recommendations were not given before 1981.

The factor of safety for seam strength in the 1981 AASHTO specifications was still 3 and the factor of safety against wall yielding and buckling was still 2. The flexibility factor for 6- x 2-in. steel corrugations was still 0.02 in./lb for pipe and 0.03 in./lb for pipe-arch, but a new arch category was added. For corrugated arches, the flexibility factor maximum was set at 0.03 in./lb. Since at least 1969, aluminum conduits have been included in the AASHTO specifications along with steel. When aluminum is used, a much higher flexibility factor is permitted because the modulus of elasticity of aluminum is much lower than that of steel. However, this is an insufficient explanation because if aluminum culverts can be constructed with this higher FF, then so can steel culverts.

For long-span structures, the soil bin was eliminated as an acceptable special feature because of problems with performance. In addition, the wall-crushing or yielding criterion was not eliminated as before. The soil types and compaction permitted for long-span structures in 1981 are more restrictive than those for non-long-span structures but are unchanged from 1977.

For long-span structures, the requirements for the zone size of the backfill were also changed in 1981. This material was termed "select structural backfill" and the extent was said to be dependent on the quality of the adjacent embankment. For ordinary installations with good-quality, well-compacted embankment or in situ soil adjacent to the structural backfill, a width of structural backfill of 6 ft beyond the structure is sufficient. The structural backfill should also extend to an elevation 2 to 4 ft over the structure. It is not necessary to excavate native soil at the sides if the quality of the native soil is already as good as the proposed compacted sidefill. The soil over the top should also be select and carefully and densely compacted.

The AASHTO specifications were rewritten in 1983. However, the technical changes were not extensive. For the dead-load pressure (λh) the value of λ was designated as 120 lb/ft³ for flexible culverts in trench or on yielding foundation if untrenched. For culverts untrenched on unyielding foundation a special analysis is required. The nature of this analysis is not explained. Otherwise the loading for determining wall thrust is essentially the same as that in previous AASHTO specifications.

The design specifications in 1983 were subdivided into three sections, to distinguish corrugated metal pipe with riveted, welded, or lock seam fabrication from bolted structural plate structures and from long-span structural plate structures. The first two sections have the same factors of safety for each of the categories, which are wall yielding, buckling, and seam strength. The values are unchanged from the previous year. For the first section, the flexibility factors are given only for corrugations of less than 1 in. depth. For the second section, the flexibility factors are given only for 6 x 2 in. for steel and for 9 x 2.5 in. for aluminum. In both cases the flexibility factor values are unchanged

from 1981. The seam strength values for Sections 2 and 3 are the same and also unchanged from 1981.

A summary of some of the AASHTO design factors is given in Table 2.

CONCLUSIONS

In this paper an attempt has been made to trace the evolution of the national conduit design and construction specifications during the past 15 years with emphasis on the structural plate sizes. The following conclusions contain some of the main observations and a brief evaluation of them. Although the paper deals only with the specifications, it is equally important to recognize that compliance with the specifications is essential to success.

TABLE 2 Summary of AASHTO Design Factors for Ordinary Structural Plate Conduits

Factor	1969	1977	1978	1981	1983
Factor of safety					
Wall yield	?	?	2	2	2
Wall buckling	2	2	2	2	2
Seam strength	4	3	3	3	3
Flexibility factor ^a					
Arch	?	?	?	0.03	0.03
Pipe arch	?	0.03	0.03	0.03	0.03
Other	0.02	0.02	0.02	0.02	0.02

Note: ? = value unknown.

^aInches per pound for 6- x 2-in. corrugation with steel.

In 1971, AISI assumed positive arching of the earth load when the height of cover exceeded the diameter. This provision was eliminated in 1983, thus increasing the design earth load on conduits for this situation.

The AISI specifications give a minimum compaction requirement of 85 percent standard test (T-99) density, although a higher value is preferred. In the AASHTO specifications compaction requirements for ordinary conduits were not suggested until 1981 when it was recommended that a granular backfill compacted to 90 percent standard test density be used. For the new long-span category AASHTO requires 90 percent modified test (T-180) density, which is approximately equivalent to 95 percent standard (T-99), and only granular fill is permitted around the conduit.

A compaction level of 85 percent standard test density is entirely inadequate and should not be permitted in any specifications. Although reputable construction specifications do not use a low value, the AISI handbook may be interpreted as indicating that 85 percent might be acceptable for some installations. Even 90 percent standard test density should not be routinely prescribed.

Another deficiency in the specifications is that the amount of compaction required is not changed with the soil type. It is well established that the stiffness and strength of compacted soil varies greatly with the specific type of soil and moisture content for the same compaction effort. Yet conduit specifications do not recognize this fact even though stiffness and strength rather than density are the important properties. This is an area in which the specifications could be improved.

The compaction specifications are also inadequate in not providing guidelines for compaction control. Furthermore, the compaction specifications are ambiguous in not defining the statistical meaning of a given percent density. The specified value cannot be correctly interpreted to mean the minimum density

for the entire fill, because the normal variability of field density makes this impossible to achieve in practice. It might reasonably be taken to mean the average density. When the intent is unstated, the density level achieved is not unique for a given specification but varies with the inspection procedure. Thus this is another area of the specifications in which movement is needed.

An example of decreased restriction over the years is the specified layer thickness for fill compaction. Initially 6-in. layers were prescribed. More recently 6- to 12-in. thickness is allowed. This is satisfactory if the compaction equipment is suitable. However, heavy compaction equipment cannot be used close to large flexible conduits. Thus a 12-in. lift is generally thicker than desired for culvert backfill. Specifications are also not always clear whether the stated thickness is before or after compaction. The intent should be clarified.

In the earlier specifications gravelly and sandy soils are indicated as preferred for backfill, but most local fill, including silts and low-plasticity clays, was acceptable if properly placed. Specifications also called for well-engineered fill similar to that used for highway embankments. However, highway embankment specifications are not adequate to meet the structural requirements of conduit backfill.

Typically culvert backfill is not engineered, but it is governed almost universally by the same minimal requirements regardless of the conditions in the particular situation. In the design of the backfill, including type and compaction, such factors as the following must be considered in each case:

1. Ability to withstand the conduit pressure with limited long-term deformation,
2. Potential alteration in properties over time caused by frost action and moisture changes,
3. Creep characteristics,
4. Ease of compaction to required properties,
5. Nature and position of existing ground, and
6. Foundation conditions.

Thus satisfying performance is hard to achieve, particularly for the larger culverts, if the fill around the conduit is not granular (primarily sands and gravels). The extent to which the backfill soil type can depart from these select conditions needs careful study.

Undoubtedly recognition of the inadequacy of the specifications for backfill type led to the eventual change to the much more restrictive conditions. Now AASHTO recommends only granular backfill, with even tighter restrictions for long-span structures. Further improvement in the specifications would result from differentiating within this category based on the specific in-place properties of the fill.

Initially the width of the backfill zone adjacent to the conduit was set at one diameter or one span. This was found to be excessive for large structures and hence was relaxed for the long-span category. However, no rational procedures are given for this important parameter. It is uncertain what the proper size of the backfill zone should be and hence this problem needs to be researched.

The design specifications have consistently used a factor of safety of 2 for wall yielding and buckling, except that AISI recommends higher values for arches. The wall-yielding criterion is concerned only with ring compression stress. Bending stresses are not considered. Design methods are needed that include the effects of bending stress, especially because these affect buckling capacity as well.

The factor of safety for seam strength has varied. AISI specified a seam strength factor of safety of 4 in 1969, which was reduced to 2 in 1971.

However, for semicircular (or less-than-semicircular) arches the seam strength factor of safety was maintained at 4. AASHO also used a factor of safety of 4 in 1969 for seam strength but by 1976 their seam strength factor of safety was reduced to 3. These reduced requirements by AISI and AASHTO were based on experience that showed seam failures to not be a problem.

Although buckling is part of conduit wall design, the criteria are based on limited research and may not be correct for the large corrugated conduits. As the structures have become larger, buckling has become a matter of greater concern. Further study of this design factor is needed to ensure safe limits. This includes a more accurate representation of live load, particularly in shallow cover applications.

Originally a 5 percent deflection limit was considered satisfactory. Later the deflection specification was eliminated by the type and placement of backfill. There is a tolerance for long-span structures on departure from design shape. Unfortunately for ordinary conduits, the specifications no longer give such tolerances even though these structures can be very large. Deflection guidelines should be given for all flexible conduits.

The flexibility factor for aluminum conduits has always been permitted to be higher than that for steel conduits. However, if a higher flexibility factor is satisfactory for aluminum, it is also satisfactory for steel. Both AISI and AASHTO have increased the allowable flexibility factor for steel conduits with 6- x 2-in. corrugations by 30 to 50 percent since this value was first established. The disadvantage of this relaxed requirement is that larger structures could be built without being governed by the more restrictive and more appropriate guidelines for long-span structures.

The long-span guidelines, which are required when the flexibility factor is exceeded, also include added special features. The original list of special features has been reduced to longitudinal stiffeners and circumferential ribs. However, these appear as alternatives, whereas they have entirely different functions. The important stiffening effect of the ribs is not provided by the longitudinal members.

Opinions are divided as to the benefits of the longitudinal stiffeners, but there is good reason to believe that when ribs are needed, without longitudinal stiffeners, adding longitudinal stiffeners does not eliminate this need. The specifications need clarification on this matter, and more research is needed to evaluate the functions of the longitudinal stiffeners.

Consideration should be given to developing a unified design and installation specification that will combine the long-span category with the non-long-span structural-plate conduits that now have up to 30 ft span. This will eliminate the somewhat arbitrary and artificial distinction between these two categories and reduce the possibility of installing large conduits under inadequate specifications.

Finally, in recognition of more restrictive conduit specifications with regard to soil conditions, a plan should be implemented to reexamine the many structures built under the older specifications to ensure that they are safe and will continue to perform properly.

REFERENCES

1. Handbook of Drainage and Construction Products. Armco Drainage and Construction Products, Inc., Middletown, Ohio, 1958.
2. Handbook of Steel Drainage and Highway Construction Products, 1st ed. American Iron and Steel Institute, Washington, D.C., 1967.
3. Handbook of Steel Drainage and Highway Construction Products, 2nd ed. American Iron and Steel Institute, Washington, D.C., 1971.
4. Handbook of Steel Drainage and Highway Construction Products, 3rd ed. American Iron and Steel Institute, Washington, D.C., 1983.
5. Standard Specifications for Highway Bridges. AASHTO, Washington, D.C., annual.

Publication of this paper sponsored by Committee on Subsurface Soil-Structure Interaction.