Review of Structural Design Methods for Aluminum Alloy Corrugated Culverts

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•A NUMBER of theories of structural design have been proposed during the last few years. This review represents a consolidation of these separate approaches into a framework from which a design method for aluminum alloy culverts may be developed. This review is limited to maximum fill height considerations and round pipe.

Flexible culvert should be analyzed in the same manner as any other engineered product. The past difficulty in absolutely defining the design limits has been due principally to the fact that the confining medium, soil, is nonhomogeneous and all too often unevenly compacted in backfilling, and thus indeterminate in value. Fill heights based upon analysis of support strength of culvert must consider the condition of the soil at the time of installation. As a general rule, once the culvert is installed, the soil, even if poorly compacted, will in time consolidate and become rigid with respect to the culvert. The culvert will then unload, reducing its support strength needs.

It should be noted that the behavior of the soil environment is a major factor in flexible culvert design. All too often theories may be proposed which make initial assumptions of soil behavior and proceed from there; in so doing the value of the analysis may be negated from the onset. The development of probable pressure and force distribution must be considered the key to accurate design analysis. It is because of the difficulty in determining soil loads that several theories of differing results may be given undue credence as the only method of design. This problem emphasizes the weight that must be given to engineering judgment in final fill height selection.

LOAD

It is generally recognized that loadings derived from Marston (2) represent as accurate a basis of design as can be attained by soils over and around culverts. The analysis of fill heights will be based on the mean condition, that of the full vertical wedge weight of the soil acting vertically and uniformly across the top of the culvert; thus,

$$W_c = \rho D H \tag{1}$$

where

W_c = weight on culvert, lb/ft;
ρ = density of soil, lb/ft^3;
D = culvert diameter, ft; and
H = fill height, ft.

SOIL

Next, the support strength of the soil should be established. This has been, and will continue to be, the indeterminate factor in design. The level of support capacity is determined by soil structure and compaction. Soils which are granular and easily compacted have excellent support strength levels. Soils which are heavy in clay or silt

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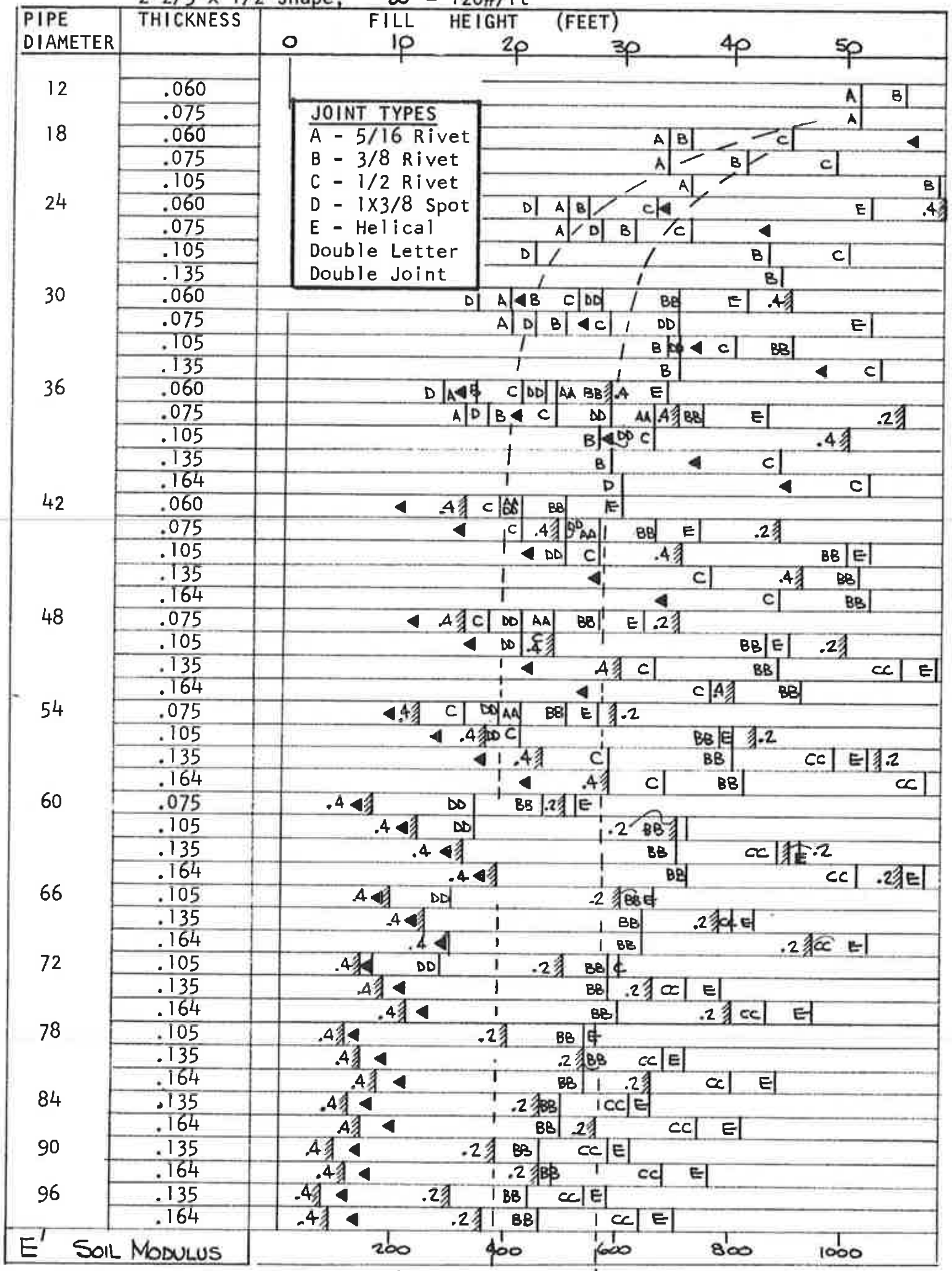
Note: This report originally contained a number of pages (Appendixes) of fill height calculations. These calculations may be obtained by writing directly to the author.

TABLE 1

COMPOSITE OF FILL HEIGHTS

Seam Strength, Ring Buckling, Total Stress, Deflection
2-2/3 x 1/2 Shape, $\omega = 120\#/ft^3$



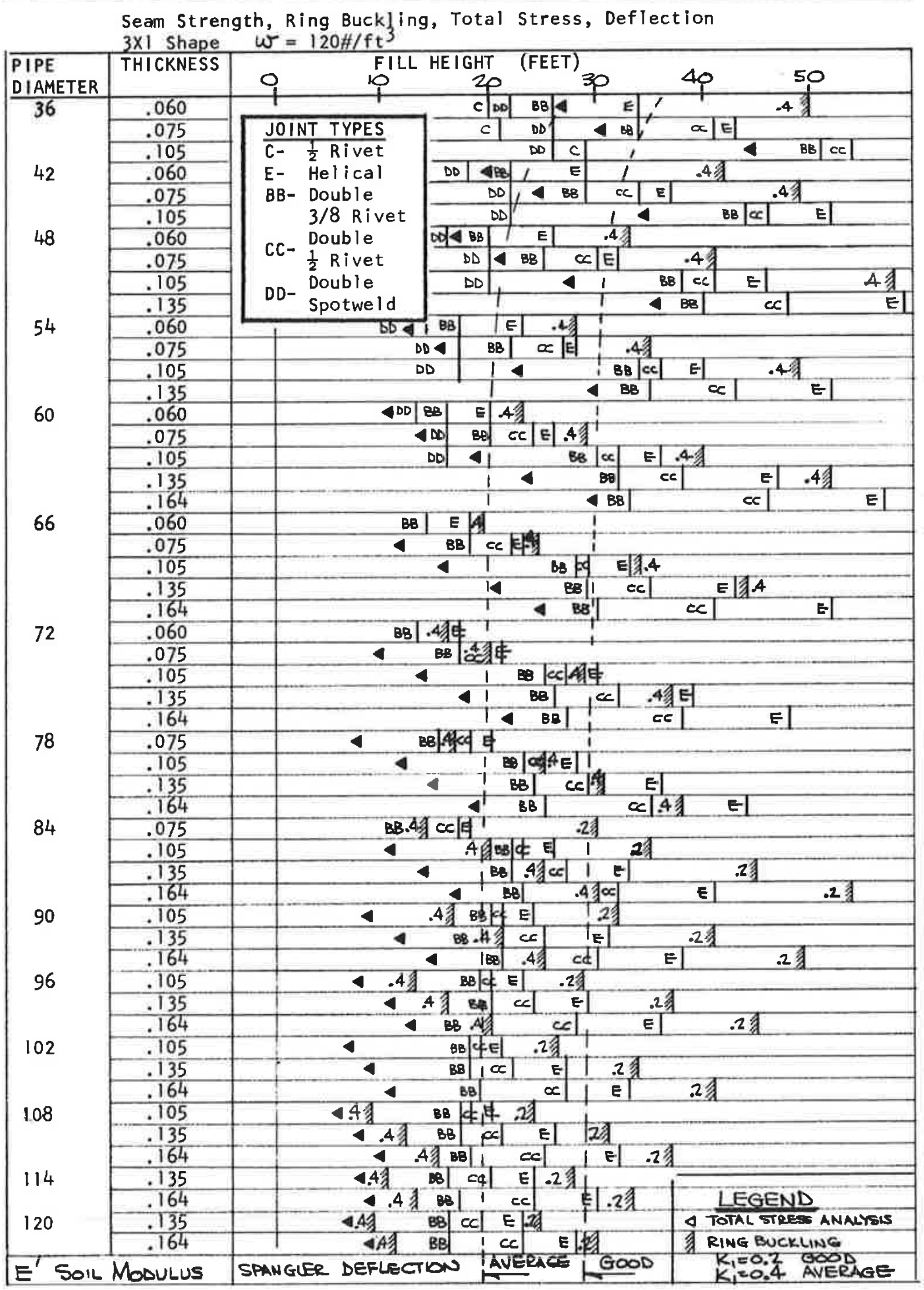
LEGEND --- SPANGLER DEFLECTION (AVERAGE | GOOD)

◄ TOTAL STRESS ANALYSIS FROM MODIFIED SPANGLER

▨ RING BUCKLING $K_1 = 0.2$ GOOD, $K_1 = 0.4$ AVERAGE

TABLE 2

COMPOSITE OF FILL HEIGHTS



content are low in support strength and difficult to compact. Significant movement under load may be anticipated for these poor structural soils. Design must be based on presumed levels of compaction, bearing in mind that the few flexible culverts which fail do so as a result of poor compaction or installation practices.

The exact level of support resistance, a combination of support strength of soil and degree of compaction, can only be approximated. Because of this limitation each theory can only be an approximation. Unfortunately, the problem of approximation is compounded, as a small change in external pressure distribution produces large changes in analytical results. It would seem that considerable restraint would have to be put on the blanket use of each theory.

DESIGN

Once a loading is established, design of the culvert should follow that of any other structure. It must be reviewed in thrust, bending, shear, deflection and instability. From these the ultimate support strength of the system may be determined. Safety factors would then reduce the solution to working levels. A series of design theories are given in Tables 1 and 2.

COMPRESSION RING

Thrust design is approximated by the compression ring theory (4). This approach presumes good compacted soil developing a uniform pressure around the periphery of the culvert and assumes the soil to be inelastic so that any shape will be rigidly maintained. With this assumption of soil behavior, it can be shown that the culvert will act as a ring in compression. The value of this approach is only as good as the assumption of uniform radial pressure from the soil. The hoop compression resists the pressure of the vertical load, therefore

$$2F = W_c \tag{2}$$

where

F = seam load, lb/ft; and
W_c = vertical load, lb/ft.

Design is based upon calculated or tested seam strengths with a safety factor of 3.0 and soil density of 120 lb/ft^3.

Coupon test data have been prepared for aluminum alloy culvert pipe for this analysis and are included and summarized in the Appendix. All types of seams, riveted, spot-welded, and helical lock seam, have been considered. Recent unpublished data indicate that stresses approaching yield strength of the metal may be used for helical culvert seam design. The composite fill heights in Tables 1 and 2 are prepared with the following code:

Joint Type	Description
A	Single row $^5/_{16}$-in. diameter rivets (this is standard for 0.060 and 0.075-in. sheet to 36-in. diameter, AASHO M 196-62I).
B	Single row $^3/_8$-in. diameter rivets (this is standard for 0.105 in. and thicker sheet to 36-in. diameter, AASHO M 196-62I).
C	Single row $^1/_2$-in. diameter rivets.
D	Single row spot welds 1 by $^3/_8$-in. oblong shape (reference AASHO M 209-63I).
E	Helical lock seam (reference AASHO M 197-62I).
AA	Double row $^5/_{16}$-in. diameter rivets (this is standard for 0.060 and 0.075-in. sheet 42-in. diameter and greater, AASHO M 196-62I).

Joint Type	Description
BB	Double row 3/8-in. diameter rivets (this is standard for 0.105 in. and thicker sheet 42-in. diameter and greater, AASHO M 196-62I).
CC	Double row 1/2-in. diameter rivets.
DD	Double row spot welds 1 by 3/8-in. oblong shape (reference AASHO M 209-63I).

DEFLECTION

A second approach to design is that of deflection analysis by Spangler (2). This method considers uniform pressure across the plane of the top of the culvert, uniform pressure resistance across the plane of the invert, and horizontal side pressures as a function of the lateral displacement. When these loads are applied to the ring and solved for deflection the equation is

$$\Delta x = \frac{K W_c r^3}{EI + 0.061 E' r^3} \tag{3}$$

where

Δx = deflection of the culvert under load, in.;
K = bedding constant;
W_c = load on culvert, lb/in.;
r = radius of ring, in.;
E = modulus of elasticity of metal, lb/in.^{2};
I = moment of inertia of culvert, in.^{4}; and
E = modulus of soil reaction, lb/in.^{2}.

Design levels were established by limiting the solution to a deflection of 5 percent of the diameter of the culvert. The 5 percent value is limited to deflection under the applied load. Design values are given in Tables 1 and 2.

BENDING STRESSES

The pressure distribution outlined by Spangler (2) may also be considered as a method of evaluation of total bending and axial stresses of the ring under the applied load. For this purpose, the pressure distribution by Spangler was modified to allow for pressure variation across the top and invert (3). Bending and axial stresses under load may be determined from

$$S_{max} = \frac{Mc}{I} + \frac{R}{a} \tag{4}$$

where

I, c, a = properties of the culvert; and
M, R = moment and thrust at the crown as a result of soil forces.

Taking a design stress of 16,000 psi for aluminum alloy culvert (yield strength/1.5) the design fill limits are calculated (Tables 1 and 2). Fill heights which exceed the calculated values may be handled if the culvert is strutted or elongated during installation.

Using the stress analysis limit as applied to flexible culvert, soil reaction pressures and the modulus of soil reaction may be related as part of the analysis. From this, using a soil displacement level of 5 percent of the diameter, the modulus of soil reaction may be related to fill height:

$$E' = 20 H \tag{5}$$

Thus, at approximately 35-ft cover an E′ of 700 psi is attained, suggesting that where fills exceed this, special care is necessary to insure that the soil used is capable of developing soil reaction E′ levels greater than 700-plus adequate safety factor.

RING BUCKLING

Several papers have described a method of design using buckling concepts. A definite need exists to consider this aspect of design, and these approaches have been included in the review. Once again an original assumption of uniform pressure distribution is made, allowing for little or no moment to be developed in the ring. This limits the accuracy of this approach as it does in the compression ring.

Compression buckling (7) may be expressed in the column buckling or Euler form for all metals as a function of column slenderness, KL/r, where L is column length, r is radius of gyration of the culvert wall, and K is a fixity constant. (See Figs. 1 and 2.) Investigation shows that

$$\frac{KL}{r} = \frac{K_1 D}{r} \tag{6}$$

where

D = culvert diameter, in.; and
K_1 = fixity of culvert wall with soil support.

Applying the theory of a fluid medium surrounding the culvert (8), a value of K_1 = 0.908 is established as the lower design limit and a value of K_1 = 0 is established for an inelastic medium as presumed by the compression ring theory. The true design values of K_1 lie between the two extremes.

Data presented by Meyerhof and Baikie (5) contained an excellent set of results which may be used to establish a level of K_1 for a condition of good granular compacted backfill.

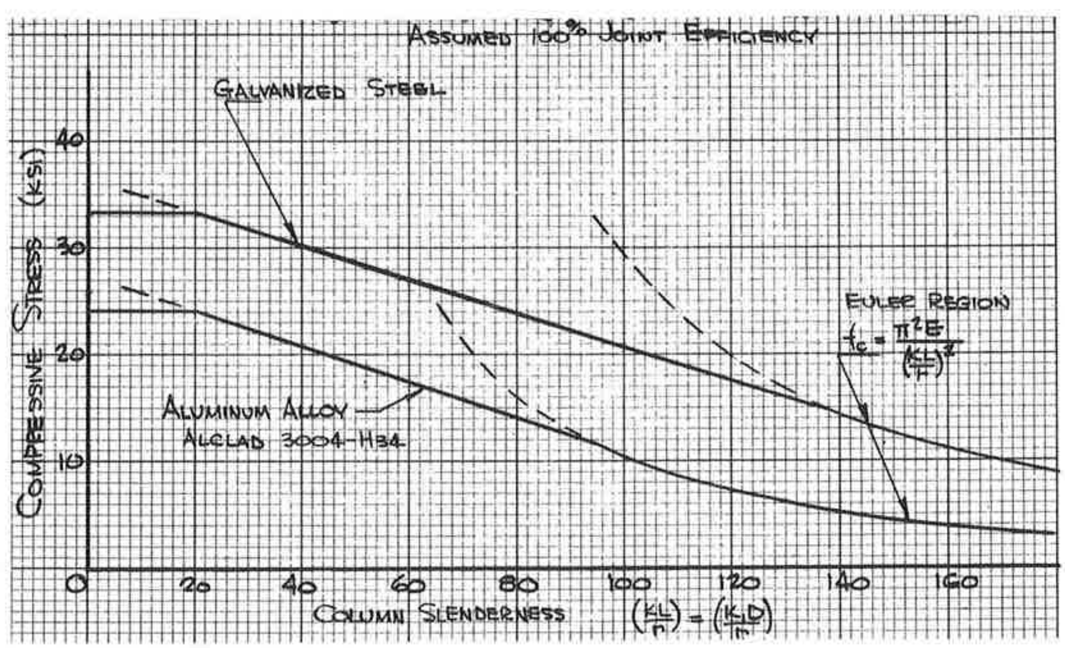


Figure 1. Curves of ultimate buckling stress, aluminum and galvanized steel culvert sheet.

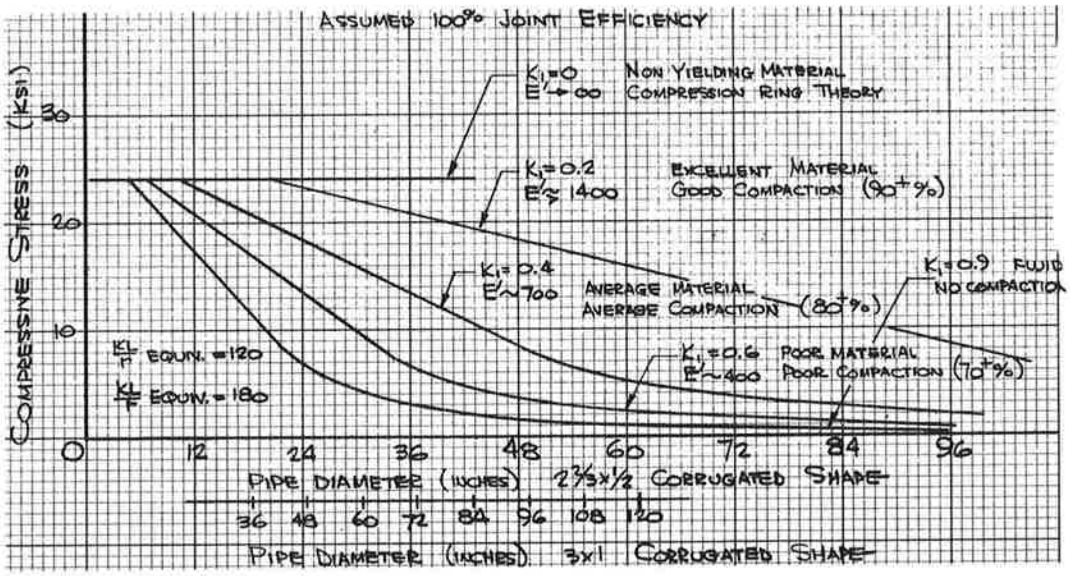


Figure 2. Effect of backfill material and compaction on compressive buckling stress, aluminum alloy, $2\frac{2}{3} \times \frac{1}{2}$-in. shape.

The data showed K_1 to be from 0.03 to 0.19 with soil modulus values of 1,530 to 12,950. From these data, design limits of K_1 of 0.2 and E' of 1,400 were selected for good installation conditions. Design stresses and fill heights were developed from the column stress curves.

Watkins (6) gives a second set of data on ring buckling values. Using small tubes and controlled but normal conditions, values of K_1 in the range of 0.4 to 0.5 were determined. From this, and field experience, a level of K_1 of 0.4 and E' of 700 were established as the basis of normal design. A value of K_1 of 0.6 is set for poor backfill conditions.

Once K_1 is established, KL/r becomes set and fill heights based on compression stresses are developed. A safety factor of 2.0 is used for this analysis with load from hoop compression. The K_1 of 0.2 is considered as a maximum limit and the K_1 of 0.4 the limit before requiring elongation or strutting (Tables 1 and 2).

FLEXIBILITY LIMIT

The ring buckling method established a means of approximating column slenderness ratios. This ratio may now be used as a means to define the flexibility of aluminum alloy culverts under load. In establishing this limit design, the average condition of K_1 of 0.4 is used.

$\frac{KL}{r}$	Culvert Flexibility Condition	Aluminum Alloy Culvert Diameter	
		$2\frac{2}{3} \times \frac{1}{2}$ in. Shape	3 × 1 in. Shape
120	Normal	≤54	<102
120-150	Flexible; elongation, strutting, or special care in handling in backfill required	60-66	>102
150-180	Very flexible; elongation, strutting, blocking, or special handling in backfill required	72-90	—

FLEXIBILITY FACTOR

The mathematical equation for an unsupported ring under external point loading has been proposed as a method of design control based upon flexibility. Such a method has no place in determination of fill heights, but is useful as a guide for relative handling flexibility in culvert placement. The equation for the loading deflection is

$$\Delta y = C \frac{W r^3}{EI} \tag{7}$$

where

Δy = deflection of culvert, in.;
W = load, lb;
r = radius of ring, in.;
E = modulus of elasticity, lb/in.^{2};
I = moment of inertia, in.^{4}; and
C = constant.

Considering a constant deflection ratio ($\Delta y/r$) and a unit load (W) the Flexibility Factor form is established as:

$$FF = \frac{D^2}{EI} \tag{8}$$

The limit levels suggested for steel are based on calculated values to include normal diameters, thicknesses, and corrugation shapes of existing products:

Shape	Steel Flexibility Factor
$2\frac{2}{3} \times \frac{1}{2}$ in.	4.33×10^{-2}
3×1 in.	3.33×10^{-2}
6×2 in.	2.00×10^{-2}

When the actual case of the unsupported ring (Eq. 7) is applied and a 5 percent deflection considered, the ring will be stressed far beyond the elastic limit of the metal. For steel, then, it is necessary to temper such a comparison of unsupported flexibility with an override of stress limitations. The values thus obtained are considerably more conservative than the limits proposed.

Recalculating the flexibility factor for steel with a stress limit of 20,000 psi, 5 percent deflection, or 500-lb/ft loading, the limits for steel must fall within either the deflection limit of D^2/EI of 7.60×10^{-2} or the stress limit of D/dt of 1,200, where d is depth of corrugation. This approach would result in much smaller diameters for a given thickness of sheet.

The deflection or stress limit analysis has a very different meaning for aluminum alloy culvert. When the initial conditions proposed are calculated, the aluminum has quite low stresses at the limits. Nonetheless, by applying the same analogy to aluminum alloy with a limit stress of 17,000 psi, the limit would be set by either D^2/EI of 7.60×10^{-2} or D/dt of 1,016. These values generally show that the lightest diameter thickness combination for aluminum alloy should be similar, a premise supported by considerable field experience.

3 × 1-IN. CORRUGATION

The commercial introduction of a 3 × 1-in. corrugated shape has been accompanied with several methods of fill height analysis of the kind reviewed previously. Calculations of fill height for 3 × 1 in. have been prepared from these theories. Joint coupons have been prepared and tested, and some pipe manufactured for structural review.

It remains to be seen where the 3 × 1-in. shape will fall in the fill height program for flexible culvert. The seam strength is no better than that of the $2^2/_3 \times {}^1/_2$-in. shape with equal fastening, and the flow friction factor is higher. However, because of the much higher wall stiffness, the 3 × 1-in. shape has advantages where bending, buckling, deflection, or instability may be considered to limit design, such as with large culverts or poor backfill material. In the larger culverts, the improvement is so marked that the maximum diameter has been suggested for increase from 96 to 120 in. and there is a justifiable opportunity to reduce metal thicknesses against the $^1/_2$-in. depth shape. This will result in reduced unit length costs and a gain in overall structural integrity for such culverts. Another strong advantage is that the need for handling aids at installation is minimized, resulting in better control of the finished installation.

SUMMARY

This review includes consideration of the various conventional methods of development of design fill heights for aluminum alloy culverts. The limits have been appraised in thrust, bending, deflection, buckling, and flexibility; each related to the assumed soil environment behavior. The data have been superimposed in Tables 1 and 2 for comparison, and from this, it is expected that fill heights may be proposed. These data are deemed sufficient to comply with the needs for good design practice at reasonable product cost to the highway industry.

The review also points out repeatedly that more knowledge of soil pressures and forces and soil distortion is necessary before more accurate design data can be made available. It is understood that some of the research is contemplated.

Similarly, a computer program now exists that would allow the treatment of soil behavior as a simulated series of equivalent spring loads. This provides a method of accurately relating ring stresses and deflection to variations in external force changes. When better knowledge of soil behavior is coupled with such a program, more accurate representation of the system will be within reach, and the results might improve on this review.

REFERENCES

1. Structural Fill Test. Kaiser Aluminum and Chemical Corporation, Oakland, Calif., 1961.
2. Spangler, M. G. Soil Engineering. International Textbook Co., 1960.
3. Koepf, A. H. Structural Considerations and Development of Aluminum Alloy Culvert. HRB Bull. 361, pp. 25-71, 1962.
4. White, H. L., and Layer, J. P. The Corrugated Metal Conduit as a Compression Ring. HRB Proc., Vol. 39, pp. 389-397, 1960.
5. Meyerhof, G. G., and Baikie, L. D. Strength of Steel Culvert Sheets Bearing Against Compacted Sand Backfill. Highway Research Record 30, pp. 1-19, 1963.
6. Watkins, R. K. Discussion of Reference 5. Highway Research Record 30, pp. 14-18, 1963.
7. Brockenbrough, R. L. The Influence of Wall Stiffness on the Design of Corrugated Metal Culverts. Highway Research Record 56, pp. 71-80, 1964.
8. Timoshenko, S. Theory of Elastic Instability. McGraw-Hill, 1936.
9. Aluminum Culvert, Technical Information. Kaiser Aluminum and Chemical Corporation, Oakland, Calif., 1964.
10. AASHO Committee on Materials. Interim Specification Designation M 196-62I. American Association of State Highway Officials, 1961-1962.
11. Federal Specification WW-P-00402. Pipe, Corrugated (Aluminum Alloy). General Services Administration, Washington, D.C., 1963.
12. Annual Meeting, Region IV, AASHO Operating Committee on Design. Panel Discussed: Structural Strength Requirements. Utah Department of Highways, Sept. 15, 1964.

Appendix

TABULATION OF RESULTS

ALUMINUM CULVERT COUPON TESTS

Specimen Shape $2^2/_3 \times 1/_2$	Thickness	Rivets	DIA	Test Load 4-Rivet Pitch	Seam Failure Load (K/ft)	Load/Rivet Spot
1172-7	060	S	$5/_{16}$	8,320	9.37	2,080
9	060	S	$5/_{16}$	8,890	10.01	2,220
6281-16	060	S	$3/_8$	8,950	10.08	2,240
17	060	S	$3/_8$	9,500	10.70	2,370
18	060	S	$3/_8$	9,450	10.65	2,360
5413-C1	060	S	$3/_8$	9,500	10.70	2,370
C1	060	S	$3/_8$	9,250	10.42	2,310
C1	060	S	$3/_8$	8,900	10.20	2,230
See last page	060	D	$5/_{16}$			
6281-31	060	D	$3/_8$	14,500	16.33	1,810
32	060	D	$3/_8$	14,750	16.61	1,840
33	060	D	$3/_8$	14,900	16.80	1,860
			Spot			
6281-1 W	060	S	$1 \times 3/_8$	7,750	8.74	1,930
2 W	060	S	$1 \times 3/_8$	6,900	7.78	1,725
3 W	060	S	$1 \times 3/_8$	8,000	9.01	2,000
1172-15	075	S	$5/_{16}$	9,050	10.19	2,260
3	075	S	$5/_{16}$	8,200	9.24	2,050
4748-C2	075	S	$5/_{16}$	9,000	10.13	2,250
C2	075	S	$5/_{16}$	9,850	11.00	2,460
C2	075	S	$5/_{16}$	10,300	11.60	2,570
5413-C2	075	S	$3/_8$	10,100	11.38	2,520
C2	075	S	$3/_8$	12,000	13.52	3,000
C2	075	S	$3/_8$	11,500	12.96	2,980
6281-19	075	S	$3/_8$	13,700	15.43	3,430
20	075	S	$3/_8$	14,300	16.11	3,570
21	075	S	$3/_8$	12,000	13.52	3,000
1172-33	070	D	$5/_{16}$	18,750	21.13	2,340
35	075	D	$5/_{16}$	17,500	19.72	2,190
41	075	D	$5/_{16}$	16,000	18.02	2,000
4748-D1	075	D	$5/_{16}$	17,000	19.17	2,120
D1	075	D	$5/_{16}$	18,250	20.60	2,280
DD2	075	D	$5/_{16}$	18,100	20.40	2,260
6281-34	075	D	$3/_8$	20,900	23.55	2,610
35	075	D	$3/_8$	20,000	22.55	2,500
36	075	D	$3/_8$	20,300	22.85	2,540
46	075	D	$3/_8$	19,000	21.40	2,370
47	075	D	$3/_8$	19,000	21.40	2,370
48	075	D	$3/_8$	19,500	22.00	2,440
5413-D2	075	D	$3/_8$	18,350	20.65	2,290
D2	075	D	$3/_8$	19,900	22.61	2,490
Shape						
6281-E1 1×3	075	D	$3/_8$	19,800	19.80	2,480

Specimen Shape $2^2/_3 \times {}^1/_2$		Thickness	Rivets	DIA	Test Load 4-Rivet Pitch	Seam Failure Load (K/ft)	Load/Rivet Spot
	Shape						
6281-E1	1 × 3	075	D	$^3/_8$	21,050	21.05	2,630
E1	1 × 3	075	D	$^3/_8$	24,000	24.00	3,000
				Spot			
6281-4 W		075	S	1 × $^3/_8$	9,250	10.41	2,310
5 W		075	S	1 × $^3/_8$	9,850	11.10	2,460
6 W		075	S	1 × $^3/_8$	11,100	12.50	2,770
	Shape						
4748-49	1 × 3	075	D	$^1/_2$	26,000	26.00	3,250
50	1 × 3	075	D	$^1/_2$	25,000	25.00	3,130
51	1 × 3	075	D	$^1/_2$	22,000	22.00	2,750
1172-17		105	S	$^3/_8$	18,800	21.20	4,700
11		105	S	$^3/_8$	17,350	19.55	4,340
6281-22		105	S	$^3/_8$	19,650	22.15	4,910
23		105	S	$^3/_8$	19,800	22.30	4,950
24		105	S	$^3/_8$	19,500	22.00	4,870
1172-27		105	D	$^3/_8$	36,100	40.70	4,510
25		105	D	$^3/_8$	37,200	41.90	4,650
6281-37		105	D	$^1/_2$	30,600	34.45	3,730
38		105	D	$^1/_2$	31,100	35.00	3,880
39		105	D	$^1/_2$	32,300	36.40	4,030
				Spot			
6281-7 W		105	S	1 × $^3/_8$	8,800	9.91	2,200
8 W		105	S	1 × $^3/_8$	6,650	7.50	1,660
9 W		105	S	1 × $^3/_8$	8,400	9.46	2,100
6281-10		105	D	1 × $^3/_8$	17,700	19.92	2,210
11		105	D	1 × $^3/_8$	16,200	18.25	2,020
12		105	D	1 × $^3/_8$	14,750	16.62	1,850
1172-1		135	S	$^3/_8$	14,250	16.05	3,560
13		135	S	$^3/_8$	14,250	16.05	3,560
6281-25		135	S	$^3/_8$	29,000	32.70	7,250
26		135	S	$^3/_8$	26,350	29.70	6,590
27		135	S	$^3/_8$	29,000	32.70	7,250
4748-1		135	S	$^1/_2$	21,950	24.75	5,490
1172-39		135	D	$^3/_8$	31,200	35.20	3,900
31		135	D	$^3/_8$	29,300	33.00	3,660
6281-40		135	D	$^1/_2$	34,750	39.15	4,350
41		135	D	$^1/_2$	40,300	45.40	5,050
42		135	D	$^1/_2$	37,000	41.70	4,630
1659-1		164	S	$^3/_8$	14,900	16.80	3,720
9		164	S	$^3/_8$	15,950	17.98	3,990
6281-28		164	S	$^3/_8$	31,700	35.70	7,930
29		164	S	$^3/_8$	30,750	34.62	7,680
30		164	S	$^3/_8$	29,100	32.80	7,260
4748-1		164	S	$^1/_2$	28,050	31.60	7,000
2		164	S	$^1/_2$	24,900	28.05	6,230

Specimen Shape $2^2/_3 \times {}^1/_2$	Thickness	Rivets	DIA	Test Load 4-Rivet Pitch	Seam Failure Load (K/ft)	Load/Rivet Spot
1659-3	164	D	$^3/_8$	36,350	40.90	4,540
4	164	D	$^3/_8$	35,850	40.40	4,480
5	164	D	$^3/_8$	30,700	34.60	3,940
6281-43	164	D	$^1/_2$	45,000	50.70	5,630
44	164	D	$^1/_2$	43,500	49.00	5,430
45	164	D	$^1/_2$	42,000	47.30	5,250
5413-D1	060	D	$^5/_{16}$	14,700	16.60	1,840
D1	060	D	$^5/_{16}$	12,100	13.62	1,510
D1	060	D	$^5/_{16}$	13,700	15.42	1,710
4748-DD1	060	D	$^5/_{16}$	12,100	13.62	1,510

COMMENTS ON COUPON TESTS

HALES LAB # 1172

1. 0.105" SPECIMENS TESTED EXTREMELY HIGH. THIS IS DUE TO AN IDEAL RELATIONSHIP BETWEEN SHEET AND RIVETS TO PRODUCE THE BEST INTERFACE FIT. DURING TEST CONSIDERABLE LOAD IS TAKEN BY FRICTION.

2. 0.135" DROPPED OFF AS THERE WAS MORE RIVET LOAD

HALES LAB # 1659

1. 0.164" WAS AFFECTED AS THE o.135" MATERIAL IN #1172 CAUSING AN APPARENT LEVENING OFF AT RIVET SHEAR LIMITS.

HALES LAB # 4748

1. ½" RIVET COUPONS GIVE VERY LOW VALUES. THIS WAS DUE TO POOR AND INADEQUATE SHEET HOLDDOWN MEANS WHEN RIVETS WERE SET SO SHEET WAS ALLOWED TO FLOW OUT IN CONE SHAPE. THESE VALUES WERE NOT USED IN STRUCTURAL ANALYSIS.

2. 14 GA RIVET SIZE IN C2 INCORRECTLY IDENTIFIED. RIVETS WERE 5/16" DIAMETER.

3. 14 GA RIVET SIZE IN D1 & DD2 ARE CORRECT AT 5/16"

HALES LAB # 6281

1. BLIND RIVETS ARE EXPERIMENTAL FOR A VERSION OF NESTABLE CULVERT AND DO NOT APPLY IN THIS ANALYSIS. STANDARD RIVETS START AT #16.

2. SPOT WELD SPECIMENS HAD NOMINAL SIZE OF 1" LONG X 3/8" MAXIMUM WIDTH ON TOP ANVIL INDENTATION IN OVAL SHAPE AND REPRESENT A GOOD LEVEL SPOTWELD.

3. 1/2" RIVET SAMPLES ARE OF GOOD COMMERCIAL QUALITY AND HAVE BEEN INCLUDED AS A BASIS FOR DESIGN.

SEAM STRENGTH

ALUMINUM ALLOY CULVERT SHEET
BASED UPON LABORATORY TESTED COUPONS

Joint	Fastener		Sheet		Ultimate Test Strength (K/ft)	Design Seam Strength Compression, S. F. = 3.0
	Size	No. Rows	Shape	Thickness		
Rivet	5/16	1	2 2/3 × 1/2	.060	9.23	3.07
				.075	9.23	3.07
	3/8	1	2 2/3 × 1/2	.060	9.90	3.30
				.075	11.22	3.74
				.105	15.72	5.24
				.135	16.20	5.40
				.164	16.62	5.54
	1/2	1	2 2/3 × 1/2	.060	12.13	4.04
				.075	13.27	4.42
				.105	18.00	6.00
				.135	24.30	8.10
				.164	27.90	9.30
	5/16	2	2 2/3 × 1/2	.060	13.50	4.50
				.075	18.00	6.00
	3/8	2	2 2/3 × 1/2	.060	16.20	5.40
				.075	20.70	6.90
				.105	31.50	10.50
				.135	32.40	10.80
				.164	33.30	11.10
	1/2	2	2 2/3 × 1/2	.075	24.70	8.23
				.105	33.30	11.10
				.135	39.60	13.20
				.164	46.70	15.57
Spot weld	1 × 3/8	1	2 2/3 × 1/2	.060	7.86	2.62
				.075	10.33	3.44
				.105	8.10	2.70
	1 × 3/8	2	2 2/3 × 1/2	.060	13.50	4.50
				.075	16.20	5.40
				.105	16.20	5.40
Rivet	3/8	1	3 × 1	.060	8.80	2.93
				.075	10.00	3.33
				.105	14.00	4.66
	1/2	1	3 × 1	.060	10.80	3.60
				.075	11.80	3.93
				.105	16.00	5.33
				.135	21.60	7.20
				.164	24.80	8.27

SEAM STRENGTH

ALUMINUM ALLOY CULVERT SHEET

Joint	Fastener Size	Fastener No. Rows	Sheet Shape	Sheet Thickness	Ultimate Test Strength (K/ft)	Design Seam Strength Compression, S. F. = 3.0
Rivet	3/8	2	3 × 1	.060	14.40	4.80
				.075	18.40	6.13
				.105	28.00	9.33
				.135	28.80	9.60
				.164	29.60	9.87
	1/2	2	3 × 1	.060	19.20	6.40
				.075	22.00	7.34
				.105	29.60	9.87
				.135	35.10	11.70
				.164	41.50	13.85
Spot weld	1 × 3/8	1	3 × 1	.060	7.00	2.33
				.075	9.20	3.07
				.105	7.20	2.40
	1 × 3/8	2	3 × 1	.060	12.00	4.00
				.075	14.40	4.80
				.105	14.40	4.80
Helical seam or sheet	—	—	2 × 1/2	.060	18.95	6.31
				.075	23.70	7.90
				.105	33.20	11.05
				.135	42.70	14.22
				.164	51.90	17.30

Note: The safety factor of 3.0 is to be combined with a soil weight of 120 lb/ft^3 in calculation of fill height.

(a) Values based on individual fastener strength as follows:

Type	Size	No. Rows	Thickness of Sheet .060	.075	.105	.135	.164
Rivet	5/16	1	2050	2050	—	—	—
		2	1500	2000	—	—	—
	3/8	1	2200	2500	3500	3600	3700
		2	1800	2300	3500	3600	3700
	1/2	1	2700	2950	4000	5400	6200
		2	2400	2750	3700	4400	5200
Spot weld	1 × 3/8	1	1750	2300	1800	—	—
		2	1500	1800	1800	—	—