Lessons Learned from Culvert Failures and Nonfailures

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A study of the deformation (flattening) of a number of flexible metal culverts, including some that collapsed and some that did not, is presented. The deformation measurements of the various arcs of the structure were used to develop a procedure for evaluating the stability of buried flexible structures on the basis of the degree of "flattening." It is a well-known fact that a flexible, buried structure depends not only on its own strength and rigidity but also on the backfill around it for support. Consequently, the importance of good backfill is relatively well understood. It is not apparent, however, how much deformation can be tolerated before flattening becomes a problem. Two failures where measurements were made as the deformation progressed are analyzed, and the degree of flattening at which failure occurred is evaluated. Several structures that have experienced considerable flattening but have not failed are evaluated. In addition to evaluating the degree of flattening that can be tolerated before problems are experienced, a correlation was made between the type of backfill and the potential for structure flattening. Soils data were acquired from project files or subsurface investigations. Charts showing the effect of type of backfill, as well as width of a select backfill envelope on structure flattening, were prepared.

Corrugated metal culverts (and other types of buried structures) are made up of various arcs of circles (Figure 1 shows an arch pipe and the various parts of circles involved). The deflected shape of the pipe reflects the bending moment and plastic hinge formation that can lead to collapse. One method of measuring the degree of flattening of a circular arc is to measure the midordinates and the chord length of the various arcs (Figures 1 and 2). By comparing the actual measurement of the midordinates with the design midordinate, a degree of flattening can be calculated. This study used a calculation of percentage change in midordinate dimension as a measure of the degree of flatness. The percentage of midordinate flattening of the top arc was then evaluated for structures that failed and also for others that did not fail. The shape is an indicator of pressure distribution required for deformation stability. A table of recommendations based on percentage flattening of the top midordinate was developed. A computer program was prepared to analyze the structure's shape and make recommendations based on the amount of flattening defined as a percentage change in midordinate dimension from the design value.

MOVEMENTS IN STRUCTURES THAT FAILED

Two structures that collapsed because of excessive flattening and for which movement data were available were studied. The characteristics of the two structures are given in Table 1.

Bowser-Morner Associates, Inc., 4518 Taylorsville Road, P.O. Box 51, Dayton, Ohio 45401-0051.

Movement data from either direct measurements of midordinates or from hook elevation readings shortly before failure were available. The midordinate flattening was calculated for the structures directly or was indirectly estimated from hook readings. Table 2 gives the top midordinate measurements and the percentage change in dimensions at various stations throughout the structures.

On the basis of the midordinate flattening data, Structure 1 collapsed at a top midordinate flattening of about 48.3 percent, whereas Structure 2 collapsed at a flattening of about 29.5 percent. The data for Structure 1 were taken about 6 months before failure and represent relatively accurate amounts of flattening at the time of failure. The data from Structure 2 represent movements taken near the time of installation of the structure and not movements at failure. On the basis of the degree of compaction and the length of time before failure, it is estimated that the flattening of the midordinates for Structure 2 was about 50 percent at the time failure.

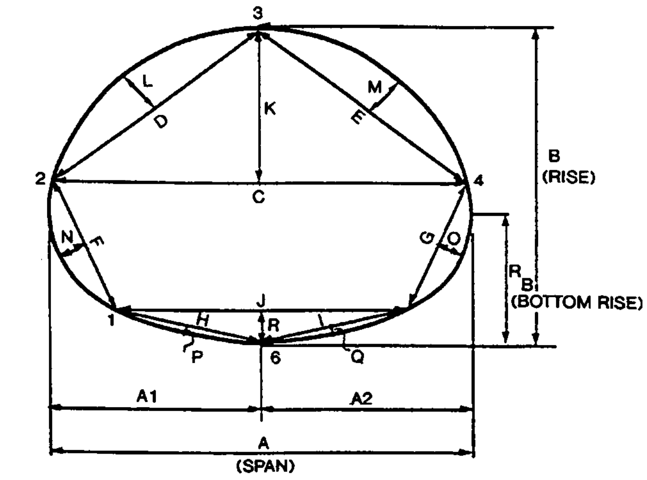
Both of these structures indicate that collapse occurred at a top midordinate flattening of from 45 to 55 percent.

MOVEMENTS IN STRUCTURES THAT DID NOT FAIL

Three long-span structures that experienced considerable flattening, and more than 900 pipe arch structures in Ohio (*1*) installed between 1951 and 1965 that experienced varying degrees of flattening, were studied. These "nonfailure" structures with large amounts of deformation (based on midordinate flattening) were studied to determine the reasonable limits of how flat a structure can become before problems are experienced. Data for the three long-span structures are presented in Table 3.

These structures were evaluated by measuring the actual midordinate and chords of the structures. The measured midordinates were compared with the design midordinate and the percentage of flattening was calculated as indicated in Table 4.

The data for these three structures indicate that midordinate flattening in various locations ranged from 21.2 to 47.4 percent. The structures did not collapse and hence provide some data on how flat (in terms of midordinate shortening) structures can become without collapsing. The 47.4 percent movement in Structure 1 was a very localized condition. Consequently, this station deformation is not a fair assessment of how much average movement can be tolerated. However, movements in the structure in other locations were as high as 21.2 percent. The movements of the top midordinates within the structures without failure varied from about 22 to about 34 percent.

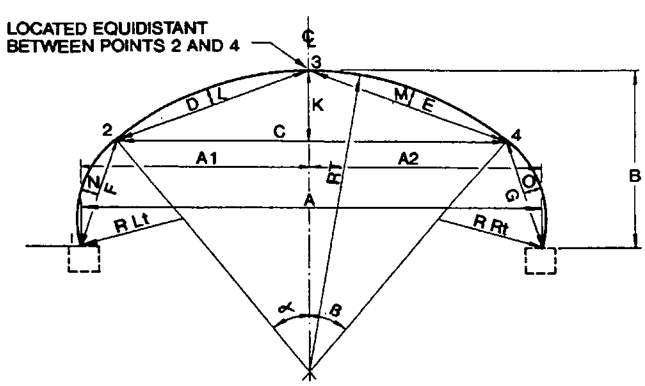


NOTES:

1. A THROUGH R REPRESENT DIMENSIONS MONITORED AT EACH STATION.
2. JOINT LOCATIONS 1,2,4 AND 5 REPRESENT CHANGE IN CURVATURE: 3 IS LOCATED EQUIDISTANT BETWEEN 2 AND 4; 6(IF ACCESSIBLE) IS LOCATED EQUIDISTANT BETWEEN 1 AND 5.
3. DIMENSIONS H,I,J,P,Q, AND R MAY NOT BE ACCESSIBLE FOR MEASUREMENT.

FIGURE 1 Typical measurements for pipe arch structure.

In addition, a study of some 900 pipe arch structures was undertaken in Ohio to evaluate the midordinate flattening. Fifty structures were selected from these 900 for a comprehensive evaluation of the top midordinates. The structures ranged in size from a span and rise of 1.8 by 1.4 m to 5.0 by 3.0 m. Most of the structures were installed between 1951 and 1965. The average age of the structures was 25 years. The percentage shortening of the three top midordinates for these structures is given in Table 5.



NOTES:

1. A THROUGH L REPRESENT DIMENSIONS MONITORED AT EACH STATION.
2. JOINT LOCATIONS 1 THROUGH 5 REPRESENT CHANGE IN RADIUS.
3. MIDORDINATES ARE: K,L,M,N,O

FIGURE 2 Typical measurements for low-profile arch structure.

One of these structures experienced a top midordinate flattening of 25 to 30 percent. Another experienced a flattening of 20 to 25 percent. Most had less than 20 percent movement. However, one of the structures sustained movements near 30 percent, and no failure occurred.

DEVELOPMENT OF RECOMMENDATIONS

The information from the evaluated structures, both those that failed and those that did not fail, was used to develop a table of movements versus recommendations on the basis of top midordinate reduction (see Table 6). The table was designed to yield recommendations for load derating to closure of a structure on the basis of top circumference flattening. The cessation of deformation with time is a measure of continuing satisfactory performance.

COMPUTER PROGRAM TO ANALYZE FLATTENING

A computer program (referred to as MULTSPAN) was developed to rapidly assess midordinate flattening within structures. A data base of all sizes and shapes of structures with the design values of midordinates, radii, and other pertinent information was prepared. One can enter the program with either the structure designation or with the design rise and span and type of structure, and the program will look up the design midordinates. The data base includes all the standard shapes and types of structures. If the design structure and the field measurements of midordinates and chords are entered, calculations of percentage change in dimension and recommendations (as indicated in Table 6) are output. Table 6 is built into the program, and the output is in the form of a recommendation. Table 7 gives sample input data for the MULTSPAN program. Table 8 gives the summary output data along with the recommendations.

The program will also print out the measurement data for each station measured along the pipe, along with the percentage of movements at each individual station. The program allows computation of the percentage of midordinate change as compared with a set of readings at any given time as opposed to the design data. This feature allows continued tracking of flattening of the structure so that an assessment can be made as to whether the pipe is likely to reach an ultimate failure point, and over what period of time.

TABLE 1 Characteristics of Failed Structures

Parameter	Structure No. 1	2
Type	Pear	Low Profile Arch
Span (m)	8.56	11.58
Rise (m)	8.48	7.16
Thickness (mm)	7.0	6.0
Corrugation (mm)	152 x 51	152 x 51
Fill Over Top (m)	2.74	1.83
Type of Backfill	"On-Site" Soil CL-ML	"On-Site" Soil SP-ML
Degree of Compaction	90%	59% - 89%
Foundation	Soft Soil	Relatively Hard Soil

1m = 3.281 feet
1mm = 0.039 inch

TABLE 2 Midordinate Flattening Before Failure

Structure Station	Top Center Chord (C) Design	Top Center Chord (C) Meas.	Top Midordinates (mm) Center (K) Design	Center (K) Meas.	Left (L) Design	Left (L) Meas.	Right (M) Design	Right (M) Meas.	Critical Diff. %
Structure #1:									
1	6258	6453	844	436	213	192	213	134	+48.3
2	6258	6453	844	463	213	165	213	128	+45.1
3	6258	6447	844	469	213	152	213	152	+44.4
4	6258	6459	844	491	213	165	213	146	+41.8
5	6258	6440	844	521	213	177	213	143	+38.2
6	6258	6428	844	536	213	192	213	140	+36.4
7	6258	6407	844	576	213	213	213	155	+27.6
8	6258	6376	844	680	213	201	213	165	+23.3
9	6258	6343	844	902	213	201	213	171	+20.5
10	6258	6325	844	802	213	219	213	149	+30.4
11	6258	6331	844	792	213	204	213	152	+29.0
Structure #2:									
0	9400	9403	1710	1547	442	466	442	311	+29.5
4	9400	9245	1710	1734	442	475	442	354	+19.9
9	9400	9403	1710	1573	442	405	442	372	+15.7

1mm = 0.039 inches

PREDICTIONS OF MOVEMENT OF STRUCTURE BASED ON BACKFILL DATA

A companion computer program, SOILEVAL, was developed (*2*) to predict the degree of flattening of a structure on the basis of backfill data. For several of the structures studied, soils data were either available or borings were made to obtain soils data. This information was used to correlate the type of soil and degree of compaction with percentage flattening of the structures.

The form of the equation used in the SOILEVAL model to evaluate soil-structure interaction is

$$\Delta y = \frac{A\ \Delta W\ \mathrm{SF}}{I/r_a^3 + B(E'/E)} \leq F_s\ \Delta W\ \mathrm{SF} \qquad (1)$$

where

- Δy = maximum expected deflection at the crown of the structure;
- F_s = factor of safety to take into account the variability of soil properties, equal to 1.5;
- ΔW = potential horizontal movement of one side of the structure due to compression of both backfill and original soil under the stress generated by the pipe;
- SF = shape factor, defined as the ratio between the vertical displacement of the structure at the crown and the corresponding maximum movement on one side of the structure;
- I = moment of inertia of pipe wall;
- E'/E = ratio of modulus of soil and modulus of elasticity of pipe material;
- r_a = average radius of the structure, equal to the span plus the rise divided by 4; and
- A, B = empirical coefficients statistically determined from field measurements.

The potential horizontal displacement of the structure due to soil compressibility (without any restriction due to structure stiffness) is obtained by summing the displacement calculated for each incremental layer on one side of the pipe. As in the calculation of shallow foundation settlement, the summation is extended to a distance at which the additional stress in the soil generated by the structure is less than 20 percent of the horizontal stress corresponding to the overburden pressure, or to a maximum distance of 2.5 times the rise dimension, whichever is less. The following equations are used:

$$\Delta W = \sum [W\ \Delta e/(1 + e_o)] \qquad (2)$$

TABLE 3 Characteristics of Nonfailed Structures

Parameter	Structure No. 1	2	3
Type	Pipe-Arch	Aluminum Pipe Arch	Low Profile Arch
Span (m)	3.25	3.94	11.56
Rise (m)	2.10	2.29	4.75
Thickness (mm)	3.5	2.5	6.0
Corrugation (mm)	152 x 51	127 x 25	152 x 51
Fill Over Top (m)	7.5	3.4	1.0
Type of Backfill	Cohesive Soil	Silty Clay (ML)	Silty Sand with Gravel (SM)
Degree of Compaction	95%	90%	90%
Foundation	Clayey Sand	Silty Clay	Silty Clay

1m = 3.281 feet
1mm = 0.039 inch

$$\Delta e = C_c \log \frac{K_o P'_v + \alpha P_h}{K_o P'_v} \quad (3)$$

$$\alpha = 10^{(-0.45d/R)} \quad (4)$$

$$P_h = P_v r_t / r_s \quad (5)$$

where

W = initial width of an incremental layer;
Δe = potential decrease in void ratio;
e_o = initial void ratio, not affected by the supplementary pressure induced by the structure;
C_c = compression index of the soil (backfill or original soil beyond the backfill);
K_o = coefficient of earth pressure at rest;
P'_v = effective overburden pressure at the level of calculation (i.e., approximately in the middle of the loaded area by the structure);
α = influence coefficient at the distance from the structure corresponding to the middle of a given incremental layer;
P_h = supplementary pressure on the side plates of the structure induced by the downward movement of the structure's crown;
P_v = total vertical pressure due to the soil dead load on the top of the structure, considered approximately equal to the unit weight of the backfill times the depth of cover;
R = rise of the structure;
r_t = top radius of the structure; and
r_s = side radius of the structure.

TABLE 4 Percentage of Midordinate Flattening of Nonfailed Structures

Structure Station	Midordinate Deformation (mm)								
	Center (K)			Left (L)			Right (M)		
	Design	Meas.	% Diff	Design	Meas	% Diff	Design	Meas.	% Diff
Structure #1:									
0+00	1366	1335	+2.4	387	329	+14.7	387	357	+8.1
0+20	1366	1335	+2.4	387	357	+8.1	387	363	+6.4
0+40	1366	1320	+3.3	387	335	+13.0	387	363	+6.4
0+60	1366	1320	+3.3	387	329	+14.7	387	363	+6.4
0+80	1366	1320	+3.3	387	335	+13.0	387	357	+8.1
1+00	1366	1320	+3.3	387	344	+11.4	387	351	+9.7
1+20	1366	1320	+3.3	387	344	+11.4	387	357	+8.1
1+40	1366	1335	+2.4	387	317	+17.9	387	344	+11.4
1+60	1366	1335	+2.4	387	344	+11.4	387	351	+9.7
1+70	1366	1195	+12.6	387	204	+47.4	387	451	-16.5
1+80	1366	1295	+5.2	387	305	+21.2	387	344	+11.4
2+00	1366	1295	+5.2	387	317	+17.9	387	351	+9.7
2+20	1366	1265	+7.5	387	317	+17.9	387	344	+11.4
2+40	1366	1259	+7.9	387	317	+17.9	387	351	+9.7
2+60	1366	1237	+9.3	387	305	+21.2	387	344	+11.4
2+80	1366	1259	+7.9	387	311	+19.6	387	344	+11.4
3+00	1366	1265	+7.5	387	317	+17.9	387	344	+11.4
3+20	1366	1259	+7.9	387	317	+17.9	387	329	+14.7
3+40	1366	1271	+7.0	387	305	+21.2	387	329	+14.7
3+60	1366	1277	+6.5	387	305	+21.2	387	329	+14.7
3+80	1366	1277	+6.5	387	344	+11.0	387	305	+21.2
Structure #2:									
3+75	594	549	+8.0	152	165	-7.3	152	137	+10.6
4+00	594	539	+9.0	152	162	-5.3	152	143	+6.6
4+25	594	530	+10.5	152	174	-13.3	152	122	+20.5
4+50	594	436	+21.9	152	192	-25.2	152	137	+10.6
4+75	594	424	+28.5	152	171	-11.3	152	101	+34.4
5+00	594	585	+1.3	152	125	+18.5	152	137	+10.6
5+25	594	564	+4.9	152	186	-21.3	152	131	+14.5
5+50	594	558	+5.9	152	168	-9.3	152	128	+16.5
5+75	594	582	+1.8	152	189	-23.2	152	134	+12.5
6+00	594	591	+0.3	152	180	-17.3	152	137	+10.6
6+25	594	579	+2.3	152	192	-25.2	152	134	+12.5
6+50	594	594	-0.3	152	162	-5.3	152	149	+2.6
6+75	594	573	+3.3	152	183	-19.3	152	125	+18.5
7+00	594	555	+6.4	152	189	-23.2	152	119	+22.5
7+25	594	527	+11.1	152	171	-11.3	152	116	+24.5
7+44	594	521	+12.1	152	189	-23.2	152	125	+18.5
Structure #3:									
1+00	1670	1533	+8.2	430	497	-15.4	430	469	-9.0
1+12	1670	1518	+9.1	430	402	+6.5	430	442	-2.7
1+24	1670	1542	+7.7	430	375	+12.9	430	418	+3.0
1+36	1670	1503	+10.0	430	375	+12.9	430	393	+8.7
1+48	1670	1567	+6.2	430	369	+14.3	430	411	+4.4
1+60	1670	1579	+5.5	430	335	+22.1	430	408	+5.1
1+72	1670	1585	+5.1	430	387	+10.1	430	424	+1.6
1+84	1670	1579	+5.5	430	384	+10.8	430	442	-2.7
1+96	1670	1564	+6.4	430	418	+3.0	430	454	-5.5

NOTE: + = Flattening
- = Peaking
1mm = 0.039 inch

TABLE 5 Percentage Shortening of 50 Pipe Arches

Percentage Shortening of Midordinate %	# of Structures
0-10	35
10-15	9
15-20	4
20-25	1
25-30	1

A number of soil properties must be known or properly estimated, both for the backfill and the original soil. They are e_o, C_c, K_o, and the unit weight. The program gives the option of entering these as input data or estimating them on the basis of various levels of knowledge of soil conditions.

Potential backfill and original soils have been divided into seven categories, and the geotechnical parameters have been estimated for each category. These parameters versus soil type have been built into the program so that by choosing a soil category on the basis of simplified soils data, the appropriate geotechnical indexes are automatically used. If more precise data are available, the program allows the direct input of the soil parameters. Table 9 gives the soil categories and corresponding C_c values built into the model.

These soil types were incorporated into the SOILEVAL computer program (*3*) with appropriate shape factors for the structure. The program can predict the degree of flattening that may occur once a type of backfill and compaction are determined. The program was set up to use actual compaction data, standard penetration test data, actual consolidation data, or a default soil (No. 1–7) to analyze the structure. The SOILEVAL program was then tested on various structures for which the vertical movement was known. Computed movements, using the program, were compared with actual movements. Table 10 gives a comparison of the measured vertical movement versus the movement computed by the SOILEVAL program.

Table 10 indicates that relatively close correlation was obtained. In this study, information from previous borings was available, borings were made as part of the study, or initial data were available to categorize the backfill soil and the original soil outside the backfill envelope. The computed and actual values show relatively good correlation, indicating that the SOILEVAL program yields useful information on predicted flattening of structures as a function of backfill condition.

The program can be used to evaluate an in-place structure experiencing movement or various types of possible backfill (being considered during design) to predict the degree of flattening that will occur if a certain type of backfill is used. On the basis of the SOILEVAL program, curves of predicted movement versus degree of compaction for various types of backfill material were prepared (see Figure 3).

Figure 3 allows a quick review of the expected vertical deflection (also in terms of percent change in top midordinate dimension) for various types of backfill at various degrees of compaction for a particular structure.

The material outside the select backfill envelope immediately around the structure also contributes to flattening of the structure by allowing the sides of the structure to move out and the top to move down. SOILEVAL was used to develop graphs of the degree of midordinate flattening on the basis of the type of material outside the select backfill envelope. The soil outside the select backfill may be original soil or embankment fill. Figure 4 was prepared on the basis of the geometry of the selected backfill on one side of the pipe and the type of material for the original soil. The typical culvert installation is shown in Figure 5.

These charts provide a quick reference value for evaluating the type of backfill, the degree of compaction, the width of any select backfill, and the effect of various types of material outside the select backfill on structure movement.

CONCLUSIONS

The technique of measuring midordinates and the evaluation of percentage changes in midordinate dimension of various arcs of the structure provide a relatively simple method of evaluating in-place distortion of flexible metal structures. The allowable midordinate deflections and associated recommendations take into account the failure and nonfailure of actual structures. The recommendations provide a factor of safety in the evaluation process. The overall safety of the structures is generally a function

TABLE 6 Percentage Midordinate Reduction and Remedial Action

Midordinate % Reduction	Depth of Cover (m)	Recommended Action
<15	Any	No action required.
15 - 20	Over 1.8	No action required.
15 - 20	Under 1.8	Monitor on 6-month interval.
20 - 25	Over 1.8	Reduce legal load to 90% of H-20 and monitor on 6-month intervals.
20 - 25	Under 1.8	Reduce legal load to 75% of H-20 and monitor on 6-month intervals.
25 - 30	Over 1.8	Reduce load to 75% of H-20 and monitor on 6-month intervals
25 - 30	0.9 - 1.8	Reduce load to 50% of H-20 and monitor on 6-month intervals.
25 - 30	Under 0.9	Reduce load to 50% of H-20 and do detailed analysis.*
>30	Any	Close road until detailed analysis is done.

*NOTE: Detailed analysis to include soil borings to determine if additional movement of the structure can be expected.

1m = 3.281 feet

TABLE 7 MULTSPAN Sample Input of Chords and Midordinates

	Chords (mm)							
	Top			Side		Corner		Bottom
Station	Center	Left	Right	Left	Right	Left	Right	Center
	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)
5	3283	2124	2091	613	610	1326	1341	2649
6	3316	2097	2082	610	610	1332	1338	2655
7	3289	2091	2082	613	613	1323	1335	2649

	Midordinates (mm)							
	Top			Side		Corner		Bottom
Station	Center	Left	Right	Left	Right	Left	Right	Center
	(K)	(L)	(M)	(N)	(O)	(P)	(Q)	(R)
5	1305	381	405	146	143	49	58	110
6	1286	372	372	149	146	52	55	88
7	1301	378	381	143	149	55	58	98

1mm = 0.039 inch

TABLE 8 Summary of Output Data

	Design Value	Avg. Value	Max. At Value Sta.	Min. At Value Sta.	Critical % Diff.
Midordinates (mm) *					
Top Center	1527	1451	1516	1397	+8.64
Top Left	436	442	473	400	+8.23
Top Right	436	418	446	394	+9.63
Radii (mm)					
Top Center	1783	1859	1909	1760	-7.00
Top Left	1783	1756	1933	1657	-8.41
Top Right	1783	1759	1845	1625	-3.45

* Midordinate design values are computed based on design parameters or estimated based on geometric relationships. A value of zero indicates that a suitable midordinate value could not be computed because the field measurements could not be taken at the major breaks in curvature. Plus means decrease in midordinates or radius. A decrease in midordinates is considered critical.

Recommendation: Pipe shows no serious deformations - no top midordinate deflection is greater than 15% - maintain normal inspection frequency.

1mm = 0.039 inch

TABLE 9 Default Soil Types

Soil Category	Type of Soil	Class (Based on ASTM D-2487 Classification)	C_c Average Values
1	Gravel, Crushed Stone	GW, GP & Assimilated	0.01
2	Silty/Clayey Gravel	GM GC	0.02
3	Well-Graded Sand	SW	0.02
4	Poorly Graded Sand	SP	0.03
5	Silty/Clayey Sand	SM, SC	0.08
6	Silty Soils	ML, MH	0.10
7 (L)	Clayey Soils (Lean)	CL ($W_L < 50$)	0.18
7 (F)	Clayey Soils (Fat)	CH ($W_L \geq 50$)	0.35

TABLE 10 Measured Vertical Movement Versus Computed Movement

Structure No.	Soil Category: Backfill	Soil Category: Original Soil	Computed Movement (mm)-Horizontal: Backfill	Computed Movement (mm)-Horizontal: Original Soil	Vertical (total)	Measured Vert. Move. (mm)
1	7	Rock	152	0	304	286
2	7	Rock	86	0	372	424
3	1	VII	24	155	357	277
4	5	Old Bridge	125	0	250	250
5	4	Rock	06	0	12	06

1mm = 0.039 inch

of the degree of flatness of the various arcs of the structure, not of the ring compression factor of safety. Most structures will in fact show a relatively high factor of safety on the basis of ring compression, although the degree of flatness may be high. This technique, therefore, provides a reasonable and simple method of evaluating structures as to their safety.

The SOILEVAL program allows an evaluation of the potential for additional movement of structures given the soil backfill type and degree of compaction. It also provides a design tool for evaluation of various types of backfill and degree of compaction for prediction of percentage of flattening of the midordinates of the structure.

Both MULTSPAN and SOILEVAL allow an approximate prediction of the life of a structure on the basis of degree of flattening. MULTSPAN accomplishes this by projecting movements on the basis of successive movement readings. One set of readings is compared with the next set some period of time later. When several readings have been made and the amount of flattening over time has been established, a curve of flattening versus time can be plotted and predictions made of when flattening will become a problem. SOILEVAL allows a computation of the time versus flattening and also allows an estimation of the time over which flattening may become a problem. Current methods of predicting structure life on the basis of metal thickness, corrosivity of backfill, degree of corrosion, and metal loss do not take into account problems due to flattening of the arc of the structure. This analytical/empirical computer program, therefore, allows a prediction of the life of the structure on the basis of degree of flattening of the structure with time.

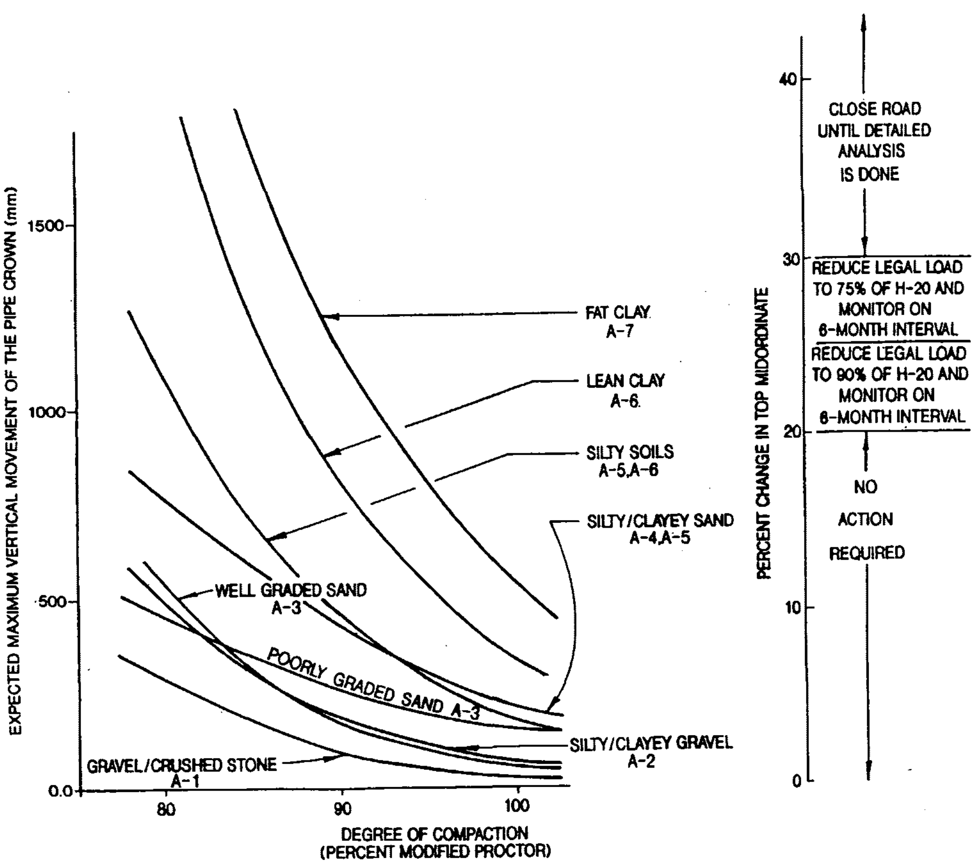


FIGURE 3 Effects of type of backfill at various degrees of compaction.

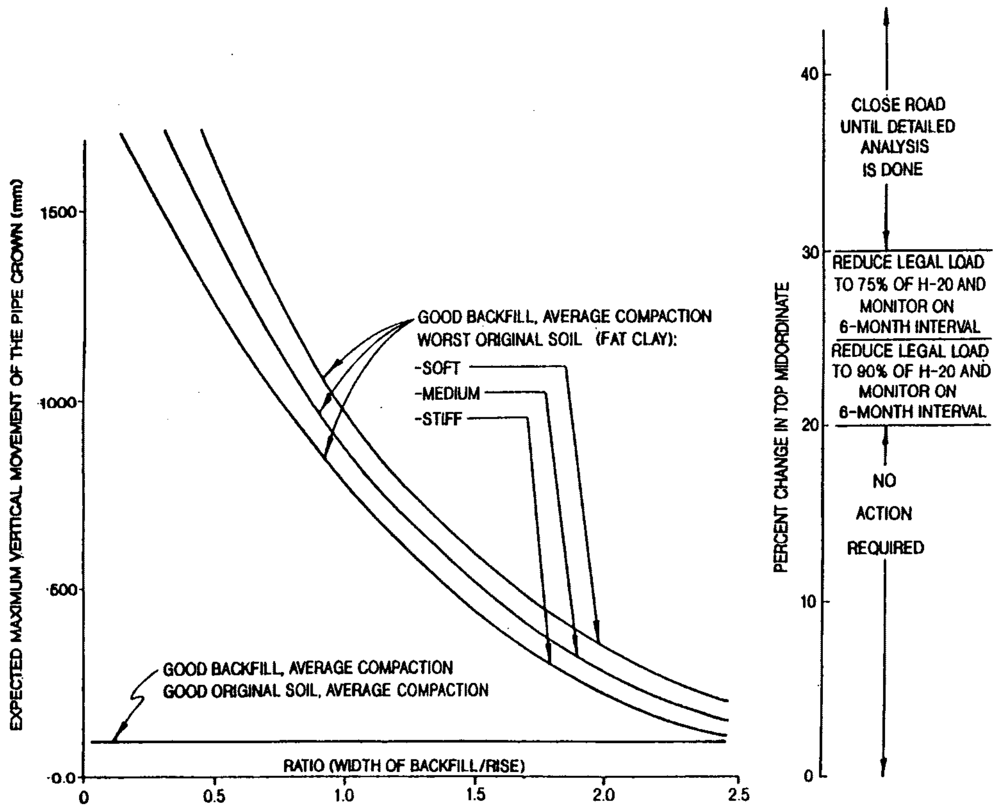


FIGURE 4 Effect of select backfill width.

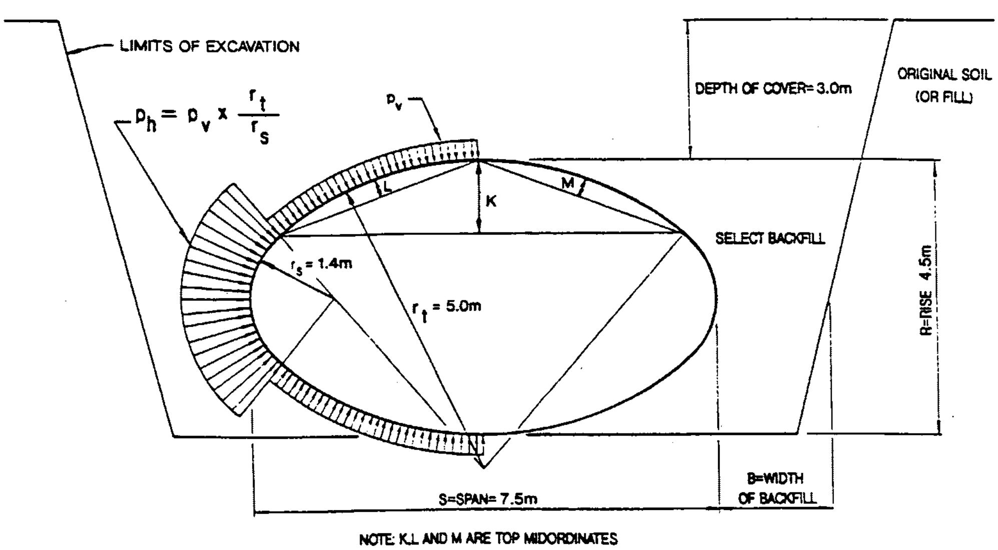


FIGURE 5 Typical culvert installation—trench condition.

The analysis procedure allows an evaluation of potential remedial action for the structure as opposed to removal of the structure. The ability of the structure to carry and transmit load is a function of the radius of the arc and the various section moduli of the corrugated metal plates throughout the structure. The MULTSPAN program calculates the radius of the arcs once the chord and midordinate are calculated. When the radius of the arc is known, the appropriate section moduli for the amount of fill over the structure can be calculated. The structure can then be structurally reinforced to provide the appropriate section modulus for the modified radius or arc of the structure.

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