Evaluation of Flexible Culvert Behavior

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A method of evaluating flexible buried structures that have experienced some degree of flattening and of estimating the potential flattening of flexible structures is presented. The integrity of flexible structures depends on maintaining their shape without becoming too flat. If a flexible buried structure becomes too flat on the top or sides, it experiences distress and might ultimately collapse. A computer program, MULTSPAN, for evaluating the degree of flatness on the basis of measurements of chords and midordinates and for recommending remedial action for deflected structures is described. The recommendations include no action, lowering the load rating of the roadway, and closing the roadway (or airfield, etc.) until further action is taken. A second program, SOILEVAL, which predicts movement of a flexible buried structure, is presented. The program uses soil type to make projections of movement. The average characteristics of seven soil types are built into the program. It is possible to access the program using standard penetration data or other information concerning the degree of compaction. It is also possible to evaluate a flexible structure that is deflected and to predict additional deflection. Whether the ultimate deflection is likely to create collapse can be determined from the evaluation. The program was calibrated with actual data obtained from several deflected or collapsed structures.

All flexible buried underground structures depend on the backfill for varying degrees of their support. It is, therefore, important that in the design and evaluation of such structures the backfill be taken into account. In many applications these structures are not periodically evaluated. Long-span structures under highways have been classified by AASHTO and most states as bridge-type structures and are required to undergo an annual inspection under a bridge inspection program. In many cases these structures were inspected in much the same way as a reinforced concrete or structural steel bridge, that is, by evaluating the structural aspects alone. Specifically, the pipes were analyzed for degree of rusting, missing bolts, torn or damaged plates, and visual structural defects. Little attention was given to deflection of the structure. These types of structures seldom fail because of structure inadequacy, but rather because of excessive deflection resulting from consolidation of backfill or soil outside the backfill envelope. As the structure applies stress to the soil, the soil consolidates by an amount dependent on compaction and allows the sides of the structure to move outward. As the sides move outward, the top moves down. As the top approaches flatness, it no longer maintains its arch structure and is no longer capable of supporting the load above it. At some point, if reverse curvature occurs, the structure collapses.

In most cases, even in evaluations that took shape into account, there were no criteria to determine when the structure shape was becoming too flat. Many times this determination was made on a strictly visual basis. A system for evaluating the flatness of such structures and making recommendations for remedial action based on deflection is needed. A simple method of predicting potential movement of a structure that is deflected is also needed. Two programs for accomplishing these objectives have been developed. They are MULTSPAN, which evaluates the degree of flatness, and SOILEVAL, which predicts soil movements on the basis of simplified soils information.

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MULTSPAN is used to evaluate the current safety of a structure, whereas SOILEVAL is used to evaluate how much additional movement a structure can be expected to undergo. MULTSPAN uses the measurements of chords and midordinates and compares the measurements with design or previous measurements.

MULTSPAN MODEL

The MULTSPAN analysis provides recommendations for remedial action on the basis of the degree of flatness of top arcs within the structure. Most of these structures are various portions of circles. It is reasonably simple to measure chords and midordinates and compare them with design values. Design values for various types of structures are built into the MULTSPAN program, or other values can be input. The program compares the measured values with the design values (or with measured values from previous inspection) and calculates the deflection as a percentage of midordinate change. Figure 1 shows a typical arch structure and the measurements that are made with such a structure.

The measurements are entered into MULTSPAN, and the degree of flatness, defined as a percentage change of the midordinate, is computed. To project the appropriate remedial action, data concerning the actual behavior of approximately 100 corrugated metal structures in Ohio and observations of several failures were examined and statistically processed (*1*). Table 1 gives the recommendations for various degrees of deflection of top midordinates.

The behavior of a flexible structure is less sensitive to changes in shape of the sides, corners, or bottom. However, large side or corner deformations (increases or decreases in side or corner midordinates) have been found to be harmful to overall stability. The criteria in Table 2 are suggested and have been implemented in MULTSPAN for the evaluation of side or corner changes in shape.

SOILEVAL MODEL

The SOILEVAL program was developed to evaluate the potential for continued movement of a structure and to predict

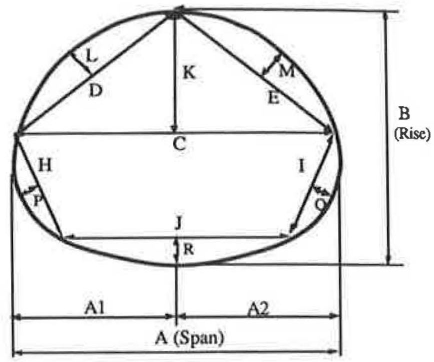


FIGURE 1 Typical measurements for a pipe-arch structure. (A through R represent dimensions to be monitored.)

a general time frame for the movement. The model is based on classical soil mechanics theory and was calibrated with actual field cases. An attempt was made to use simplified data for input to allow the program to be useful to field personnel. It is possible to use the program to evaluate an existing structure or as a design tool to evaluate the type, required width, and degree of compaction of the select backfill and the original soil.

TABLE 1 PERCENT TOP MIDORDINATE (K, L, OR M) REDUCTION AND REMEDIAL ACTION

Top Mid-Ordinate Percent Reduction	Depth of Cover (ft)	Recommended Action
<15	Any	No action required.
15 – 20	Over 6.0	No action required.
15 – 20	Under 6.0	Monitor on 6-month interval.
20 – 25	Over 6.0	Reduce legal load to 90% of H-20 and monitor on 6-month intervals.
20 – 25	Under 6.0	Reduce legal load to 75% of H-20 and monitor on 6-month intervals.
25 – 30	Over 6.0	Reduce load to 75% of H-20 and monitor on 6-month intervals.
25 – 30	3.0 – 6.0	Reduce load to 50% of H-20 and monitor on 6-month intervals.
25 – 30	Under 3.0	Reduce load to 50% of H-20 and do detailed analysis based on borings.
>30	Any	Close road until detailed analysis is done.

TABLE 2 PERCENT SIDE OR CORNER MIDORDINATE CHANGE (P AND Q IN EXAMPLE IN FIGURE 1) AND RECOMMENDED REMEDIAL ACTION

Side or Corner Mid-Ordinate Percent Reduction	Depth of Cover (ft)	Recommended Action
<30	Any	No action required
30 - 60	Any	Monitor on 6 - month interval
>60	Under 3.0	Reduce load to 50% of H-20 and perform detailed analysis, including soil borings
>60	Over 3.0	Close road until detailed analysis is done

Background

The deflection of a buried flexible structure can be predicted in accordance with the classical formula for evaluation of strain or deformation of a structural member (strain = stress/modulus of elasticity) (*2*). The equation for deflection of a flexible structure supported by backfill takes the following conceptual form:

$$\text{Structure deflection} = \frac{\text{load on structure}}{\text{structure stiffness} + \text{soil stiffness}} \tag{1}$$

Several theories to evaluate the structure-soil interaction have been proposed. Most theories for structure-soil interaction use some form of this equation.

Iowa Formula

The formula recommended by Watkins and Spangler (*3*) for predicting deflections of buried flexible pipe is

$$\Delta x = \frac{D'KW_c r^3}{EI + 0.061E'r^3} \tag{2}$$

where

Δx = horizontal deflection of the pipe (in.), considered the same as the vertical deflection;
D' = deflection lag factor, normally taken as 1;
K = a bedding constant with values between 0.08 and 0.11, depending on the bedding condition;
W_c = vertical load per unit length acting on the top of the pipe (lb/in.);
r = mean radius of the pipe (in.);
E = modulus of elasticity of the pipe material (lb/in.^{2});
I = moment of inertia per unit length of cross section of the pipe wall (in.^{4}/in.); and
E' = modulus of soil reaction (lb/in.^{2}).

The use of this formula is recommended as part of the design process for corrugated metal pipes (*4*), smooth steel pipes (*5*), polyethylene pipes (*6*), polyvinyl chloride pipes (*7*), fiberglass pipes (*8*), and generally for all buried flexible structures. Although it is confirmed that E' is not a constant but varies with depth of installation (*9*), the values suggested by Howard (*2*) are extensively used.

Other Proposed Models

Watkins et al. (*6*) summarized a number of proposed variations of the classical Iowa formula and found that all of them can be represented by a simple relationship:

$$\Delta y = \frac{\varepsilon_s\,(2r)}{A + BEI/(E_s r^3)} \tag{3}$$

where

$\varepsilon_s = P/E_s$ = vertical soil strain (soil deformation),
$P = W_c(2r)$ = vertical nominal pressure acting on top of pipe (lb/in.^{2}),
E_s = soil stiffness (lb/in.^{2}), and
A and B = empirical constants.

It was found from field tests that much of the deformation process takes place as the backfill is being placed, so for pipe deflection calculations a short-term modulus should be used. However, there may be continued deformation with time because of consolidation of the sidefill (especially with cohesive backfills), so that usually ultimate soil settlement should be included in ε_s (*6*).

Several procedures for flexible pipe deformation evaluation have been developed using finite-element methods. CANDE (Culvert Analysis, Design) is a Federal Highway Administration–sponsored computer program by Katona et al. (*10*). Three levels of sophistication are available. Level 1 is based on a closed-form elasticity solution, whereas Levels 2 and 3 are based on the finite element method. The soil-culvert interaction design method by Duncan (*11*) uses design graphs and formulas based on finite-element analysis. In the program SSCOMP, Seed and Duncan (*12*) use nonlinear finite-element analysis to model soil-structure interaction, taking into account the layerwise placement of backfill and the nonlinear stress-strain soil behavior.

The finite-element evaluations are beyond most field personnel. A simplified model for a rough evaluation of flexible buried structures that could be easily used in routine evaluation of existing structures and preliminary design of new structures was desirable. The SOILEVAL model was developed to provide this simplified model. The SOILEVAL model presented in this paper uses the classical theories of soil compressibility and settlement of shallow foundations. However, some coefficients were empirically obtained by statistical processing of field measurements.

Specifics of SOILEVAL Model

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

$$\Delta y = \frac{A\,\Delta W\,\mathrm{SF}}{EI/r_a^3 + BE'} \leq \mathrm{Fs}\,\Delta W\,\mathrm{SF} \tag{4}$$

where

Δy = maximum expected deflection at the crown of the structure (in.);
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 (in.);
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;
r_a = average radius of the structure (in.), equal to (span + rise)/4;
A and B = empirical coefficients statistically determined from field measurements; and
Fs = factor of safety to take into account the variability of soil properties, equal to 1.5.

All other parameters are as defined previously.

SOILEVAL incorporates the following characteristics of soil-structure interaction:

1. The compressibility index, coefficient of pressure at rest, initial void ratio, relative density, or degree of compaction of the soil supporting the structure are used in calculations instead of special defined characteristics (deformation lag factor or modulus of soil reaction).
2. Both the backfill and the original soil are considered to interact with the structure, up to a distance of about 2.5 times the rise of the structure laterally from the pipe wall.
3. The pipe stiffness is taken into account when it is large enough to provide resistance to deformation. However, for very flexible pipes, 150 percent of the average potential deformation of the surrounding soil is used to determine the maximum expected pipe deflection because of the potential variability of the soil properties.
4. A shape factor that represents the ratio between the decrease in rise and the corresponding lateral displacement on one side of the pipe is defined; the factor depends on the shape and dimensions of the pipe structure.

How each parameter is determined in the SOILEVAL model is described as follows.

Potential Horizontal Movement due to Soil Compressibility (ΔW)

Classical theory of settlement for shallow foundations has been used for calculating the potential horizontal movement. The fill at the side of the structure is considered as a soil column, loaded by the pressure created by the structure onto the fill (*13*). Figure 2 explains the meaning of the notation used.

The potential horizontal displacement of the structure due to soil compressibility (without any restriction due to structure stiffness) is obtained by summing the displacements calculated for each incremental layer on one side of the pipe. In a manner

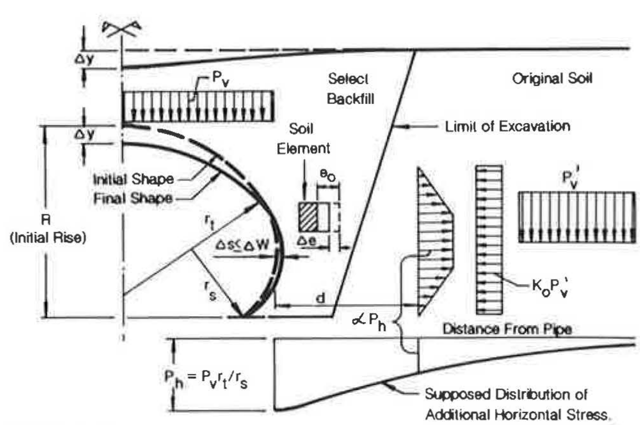


FIGURE 2 Pipe-soil interaction.

similar to the calculation of shallow foundation settlement, the summation is extended to a distance at which the additional stress in the soil generated by the pipe 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:

$$\Delta W = \Sigma[W \, \Delta e/(1 + e_o)] \tag{5}$$

$$\Delta e = C_c \log \frac{K_o P'_v + \alpha P_h}{K_o P'_v} \tag{6}$$

$$\alpha = 10^{(-0.45\ d/R)} \tag{7}$$

$$P_h = P_v \, r_t / r_s \tag{8}$$

where

W = initial width of an incremental layer (in.);
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 = the coefficient of earth pressure at rest;
P'_v = the effective overburden pressure at the level of calculation (i.e., approximately in the middle of the loaded area by the structure) (lb/in.^{2});
α = the influence of coefficient at a distance d (in.) from the structure corresponding to the middle of a given incremental layer (this parameter gives a variation of stresses close to the Boussinesq distribution for a trapezoidal loading);
P_h = the supplementary pressure on the side plates of the structure induced by the downward movement of the structure's crown (lb/in.^{2});
P_v = the total vertical pressure due to the soil dead load on the top of the structure, considered approximately equal to the product of the unit weight of the backfill and the depth of cover (lb/in.^{2});
R = rise of the structure (in.);
r_t = top radius of the structure (in.); and
r_s = side radius of the structure (in.).

A number of soil properties must be measured or estimated, both for the backfill or the original soil, including e_o, C_c, K_o, and unit weight. The SOILEVAL model gives the option of entering them as input data or estimating them on the basis of various levels of knowledge of soil condition.

Potential backfill and original soils were divided into seven categories, and the geotechnical parameters were estimated for each category. These parameters versus soil type have been built into the SOILEVAL 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 direct input of the soil parameters. Table 3 gives the soil categories and the corresponding C_c values built into the model. The values are based on well-documented case histories and information given elsewhere (*14–18*).

The relative degree of compaction of the backfill (stiffness or hardness of original soil) is necessary for an evaluation of the potential movement of a structure. The SOILEVAL model

TABLE 3 COMPRESSIBILITY INDEX VALUES

				C_c Values For:		
CATEGORY OF SOIL	TYPE OF SOIL	ASTM D-2487 CLASS	FINES CONTENT (% < #200 SIEVE)	LOOSE/SOFT MATERIAL ($C_{c,w}$)	MEDIUM ($C_{c,av}$)	DENSE/STIFF MATERIAL ($C_{c,b}$)
I	Gravel	GW,GP	<12	0.03	0.01	0.003
II	Silty/Clayey Gravel	GM,GC	12 – 50	0.05	0.02	0.008
III	Well-Graded Sand	SW	<12	0.06	0.02	0.007
IV	Poorly-Graded Sand	SP	<12	0.05	0.03	0.018
V	Silty/Clayey Sand	SM,SC	12 – 20 20.1 -30* 30.1– 50	0.06 0.16 0.33	0.03 0.08 0.17	0.015 0.040 0.088
VI	Silty Soils	ML,MH	>50	** (max 0.40)	0.007 (W_L–10) but min 0.05 and max 0.20	*** (min 0.025)
VII	Clayey Soils	CL,CH	>50	** (max 0.80)	0.007 (W_L–10) but min 0.10	*** (min 0.050)

NOTES: W_L is the liquid limit of the soil

* Default value is 30 when grain size distribution is not given

** $C_{c,w} = 2\ C_{c,av}$

*** $C_{c,b} = (C_{c,av})^2 / C_{c,w} = 0.5\ C_{c,av}$

If W_L is unknown, default values are used, which give:

$C_{c,av} = 0.10$ for Category VI soil

$C_{c,av} = 0.18$ for Category VII-a soil (lean clay)

$C_{c,av} = 0.35$ for Category VII-b soil (fat clay) provides three approaches to estimating the average degree of compaction (denseness or hardness) of soils:

- Standard penetration test results,
- Direct measurements of soil density and moisture content, and
- Design requirements or inspection records that give the degree of compaction.

A parameter that is a measure of relative density, degree of compaction or stiffness, has been developed to allow a selection of soil parameters on the basis of the stiffness of the backfill. Figure 3 shows a relationship between various criteria that can be used in SOILEVAL for defining the denseness or the stiffness of the soil.

When the standard penetration test is used to characterize the soil condition, the equations in Table 4 are considered in the SOILEVAL program. The formulas in Table 4 are based on relationships suggested in literature (*19–22*). The equations shown in Table 4 have been built into the model to calculate P when the D_{50} and average standard penetration value N of the backfill are known.

The parameters e_o and K_o may be directly input into the model, if known. If they are not known, the model provides a value based on soil category and standard penetration values (or other parameters that given an estimate of the degree of compaction) as shown in Table 5.

Shape Factor

The shape factor establishes a relationship between movement of the crown and the movement of the sides of the structure. It is defined as the ratio between the decrease in rise (Δy) and the corresponding increase in half-span (or in half-chord at the midheight of the rise in the case of circular arches, where the span is measured at the foundation level). Simple geometrical relationships have been derived by considering small but finite deformations of the pipe when chord length may be considered a constant. The relationships are given in Table 6. A factor of 0.84 was derived empirically to correct the theoretical formula for small pipe-arches on the basis of statistical processing of more than 300 field measurements.

Empirical Constants A *and* B

The parameters A and B in Equation 4 were statistically determined from field measurements. Nine carefully monitored case histories were used to estimate these values. Table 7 gives the characteristics of the structures considered in the calibration.

The best fit between the measured settlements at the crown and the computed values was found for $A = 3.6$ psi and $B = 0.0015$. The graph in Figure 4 is drawn for the best fit so obtained.

Applicability of SOILEVAL Model

Equation 4 evaluates the deflection at the crown on the basis of three main parameters: (*a*) potential movement due to soil compressibility, (*b*) pipe stiffness, and (*c*) soil stiffness. Therefore, although the calibration is based exclusively on corrugated metal structure case histories, it is believed the model can be used for materials other than steel as well.

Case histories of pipes other than steel were not available in the literature; however, data in the literature were used to verify the applicability of the SOILEVAL model to nonmetalic structures.

Truss Pipe (*23*) makes available the results of deflection measurements on about 140 thermoplastic composite pipes used for gravity-flow sanitary sewer systems. The pipes consist of a double-wall system, with concentric inner and outer walls braced by a truss-type structure. The walls and the truss struc-

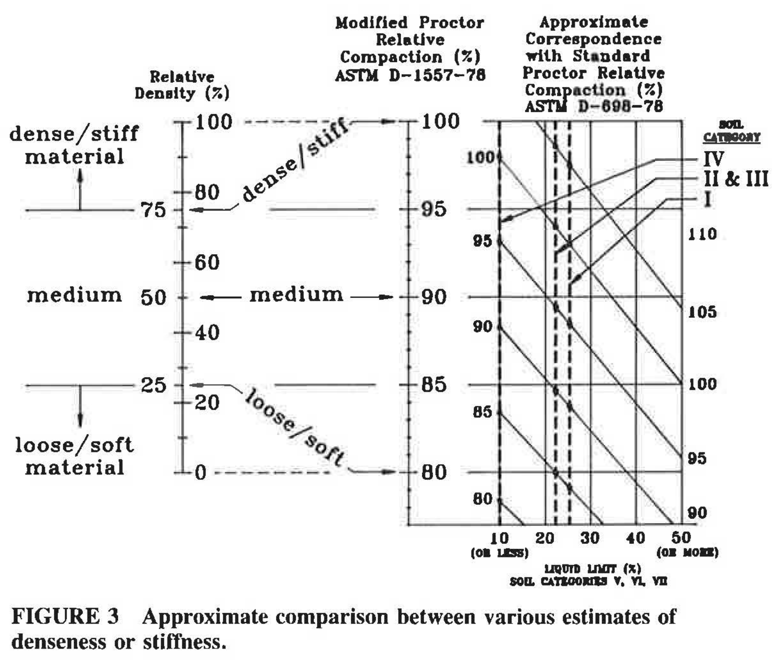


FIGURE 3 Approximate comparison between various estimates of denseness or stiffness.

TABLE 4 RELATIVE DENSITY/CONSISTENCY PARAMETER (*P*) FOR VARIOUS SOIL TYPES

SOIL CATEGORY	AVERAGE D_{50} (mm)	P: If P > 75, use P = 75; If P < 25, use P = 25
I	12.5	$43 \times \log [96.56 \times N \times D_{50}^{-0.284} \times (\sigma v')^{-0.56}]$
II	1.0	$43 \times \log [72.42 \times N \times D_{50}^{-0.284} \times (\sigma v')^{-0.56}]$
III	0.5	$43 \times \log [65.19 \times N \times D_{50}^{-0.284} \times (\sigma v')^{-0.56}]$
IV	0.3	$43 \times \log [60.36 \times N \times D_{50}^{-0.284} \times (\sigma v')^{-0.56}]$
V	0.15	$43 \times \log [54.32 \times N \times D_{50}^{-0.284} \times (\sigma v')^{-0.56}]$
VI	0.023	$43 \times \log [36.21 \times N \times D_{50}^{-0.284} \times (\sigma v')^{-0.56}]$
VII	0.007	$43 \times \log [24.14 \times N \times D_{50}^{-0.284} \times (\sigma v')^{-0.56}]$

Where:

P = a parameter which is used in the same manner as the relative density for estimation of the compressibility index

N = blows per foot in Standard Penetration Test

D_{50} = mean diameter of soil particles (mm)

$\sigma v'$ = effective overburden pressure at the test location (psf)

TABLE 5 INITIAL VOID RATIO FOR VARIOUS SOIL TYPES

SOIL CATEGORY	TYPE OF SOIL	ASTM D-2487 CLASS	STANDARD PENETRATION BLOW COUNT, N	VOID RATIO, e_o	K_o FOR: BACKFILL	K_o FOR: ORIGINAL SOIL
I & II	Gravels	GW,GP	≤ 10	0.6	0.4	0.4
		GM,GC	11-30	0.5	0.5	0.45
			≥ 31	0.4	0.6	0.5
III & IV	Sands	SW,SP	≤ 10	0.7	0.4	0.4
			11-30	0.55	0.5	0.45
			≥ 31	0.4	0.6	0.5
V	Silty/Clayey Sand	SM,SC	≤ 10	0.8		
			11-30	0.6	0.6	0.5
			≥ 31	0.45		
VI	Silty Soils	ML,MH	≤ 5	0.9		
			6-15	0.7	0.6	0.5
			≥ 16	0.5		
VII-a	Clayey Soils, $W_L < 50$ (Lean)	CL	≤ 5	1.0		
			6-10	0.8	0.7	0.6
			≥ 11	0.6		
VII-b	Clayey Soils, $W_L \geq 50$ (Fat)	CH	≤ 5	1.6		
			6-10	1.1	0.7	0.6
			≥ 11	0.7		

ture are formed of a single thermoplastic extrusion of either polyvinyl chloride or acrylonitrile butadiene styrene. The composite pipe stiffness defined by the ratio EI/r^3 is about 30 psi.

Although little information was available about the backfill soil condition, the trench dimensions, the degree of compaction, or the soil beyond the backfill, an estimate of the deflection using SOILEVAL was possible. The agreement between calculated and measured data was considered satisfactory (*24*).

Twenty-eight case histories of high-density polyethylene pipes reported by Chua and Petroff (*25*) were also evaluated. In almost all cases the predicted maximum deflections after complete consolidation of the soil were slightly greater than the maximum observed deflections, which also supports the validity of the model in these conditions (*26*).

TABLE 6 SUMMARY OF SHAPE FACTORS FOR VARIOUS TYPES OF PIPES

PIPE SHAPE	CHARACTERISTICS	SHAPE FACTOR	RANGE, (AVERAGE VALUE) FOR ARMCO/AISI PIPES
Roundpipe	$S = R$	2.0	(2.0)
Superspan Pipearch	$S \geq 20$ Feet	$0.5\left(\frac{S}{R-R_T}+\frac{S}{R_T}\right)$	2.97–4.90 (4.0)
Small Pipe-Arch	$S < 20$ Feet	$0.5\left(\frac{0.84\,S}{R-R_T}+\frac{S}{R_T}\right)$	2.53–3.99 (3.3)
Underpass	$R_T > R_B$	$0.5\left(\frac{S}{R_B}+\frac{S}{R_T}\right)$	2.28–2.60 (2.4)
Multi-Plate Arch	$R<\frac{S_B}{2}$	$\sqrt{2\left(\frac{S_B}{R}\right)^2+4}-\frac{S_B}{R}$	1.42-2.72 (2.0)
Vertical Ellipse	$R > S$	$\frac{2S}{R}$	1.79-1.82 (1.8)
Horizontal Ellipse	$S > R$	$\frac{2S}{R}$	2.70-3.82 (3.1)
Low Profile Arch	$R_T \cong 0.9R$	$0.5\left(\frac{S-S_B}{R-R_T}+\frac{S}{R_T}\right)$	1.46-1.83 (1.7)
High Profile Arch	$R_T \cong 0.6R$	$0.5\left(\frac{S-S_B}{R-R_T}+\frac{S}{R_T}\right)$	1.61–1.95 (1.9)
Pear	$R_B > R_T$	$0.5\left(\frac{S}{R_B}+\frac{S}{R-R_B}\right)$	1.88–2.30 (2.1)

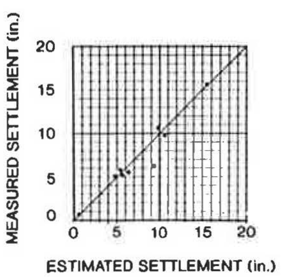
Notations in Table 6:

S = Span
S_B = Bottom Span
R_B = $R - R_T$ = Bottom Rise
R = Rise
R_T = Top Rise
r_t = Top Radius

TABLE 7 CHARACTERISTICS OF CORRUGATED METAL STRUCTURES CONSIDERED IN THE CALIBRATION

Case History No.	Type of Structure	Span (ft - in)	Rise (ft - in)	Gage No.	Height of Cover (ft)	Soil Category Backfill	Soil Category Original Soil
1	Pipearch	11' - 7"	7' - 5"	12	7.6	V	VII-a
2	Ellipse	29' - 5"	19' - 11"	5	13.5	V	N/A*
3	Pipearch	7' - 11"	5' - 7"	7	2.1	V	V
4	Pipearch	10' - 8"	6' - 11"	8	4.5	VI	V
5	Pipearch	10' - 8"	6' - 11"	10	3.7	VII-a	VII-a
6	High Profile	27' - 3"	15' - 5"	5	11.5	VII-a	Rock
7	High Profile	27' - 3"	15' - 5"	5	29.0	VII-a	Rock
8	Pipearch	10' - 8"	6' - 11"	7	9.3	V	V
9	Pipearch	10' - 8"	6' - 11"	7	9.4	V	V

*Bridge Abutments



Case History Number	Measured Settlement at Crown (in)	Estimated Settlement at Crown (in)
1	7.7	8.0
2	9.8	10.1
3	1.3	1.1
4	5.0	4.9
5	5.4	7.1
6	11.3	11.0
7	16.7	16.3
8	6.1	5.3
9	5.8	5.7

FIGURE 4 Model calibration: measured versus estimated displacement at crown.

CONCLUSIONS

1. MULTSPAN provides a simplified method of evaluating structures on an annual basis so that problems can be anticipated long before they occur and remedial action can be taken.

2. SOILEVAL provides a simplified semiempirical method of predicting movement of flexible buried structures. The program has been found useful in predicting future movements of pipes that have experienced some degree of movement.

3. SOILEVAL can be used as a design tool to design the backfill or the structure given a certain type of backfill. It can also be used to design the width of the select backfill.

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