# THE IOWA FORMULA
# WHAT IT IS — AND IS NOT

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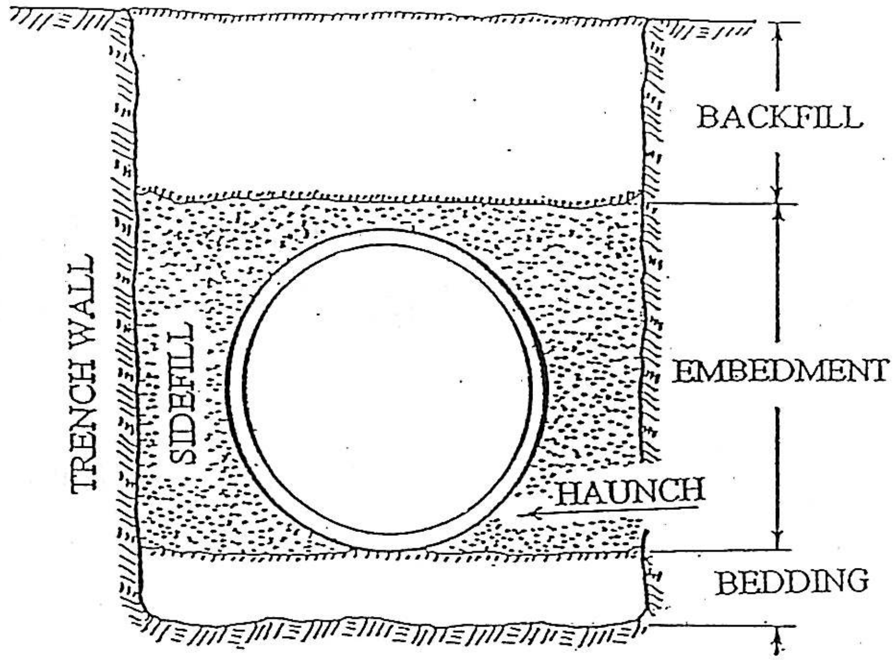
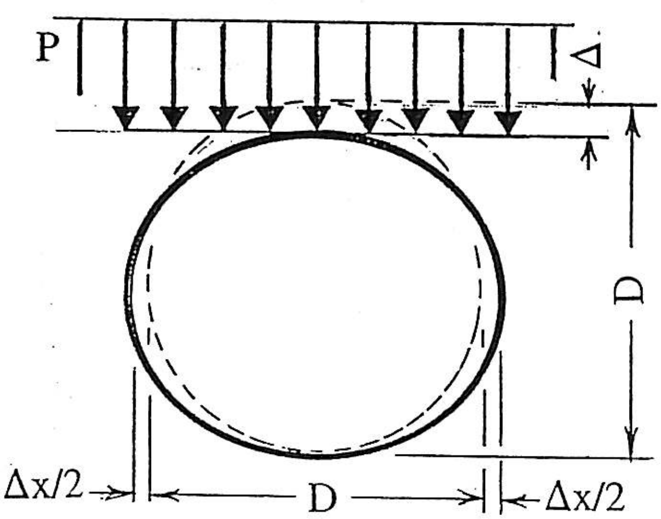


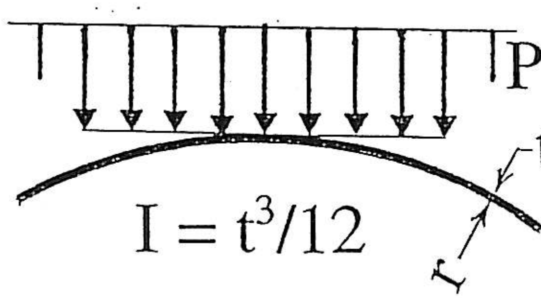

Figure 1. Nomenclature for buried pipe.




IOWA FORMULA

$$d(\%) = \frac{10P}{\Sigma(EI/r^3) + 0.06E'}$$

PIPE SOIL




$$I = t^3/12$$

Figure 2. Notation for analysis of buried flexible pipe according to Spangler's Iowa Formula.

## IOWA FORMULA — WHAT IT IS, AND IS NOT

M.G. Spangler (1941), is the father of buried flexible pipe design and analysis. He recognized that flexible pipe deflects under soil load and develops horizontal soil support. Pipe-soil interaction is the basis for the structural behavior of buried flexible pipes. See Figure 1. Spangler first published his Iowa Formula for predicting the ring deflection in 1941. Initially flawed, the Iowa Formula was modified by Watkins (1958) and published in the form,

$\Delta x = D_f K_s W_c r^3/(EI + 0.061E'r^3)$ IOWA FORMULA FOR HORIZONTAL DEFLECTION

where (See Figure 2) ..... (1)

- d = ring deflection = $\Delta y/D$ based on vertical decrease in diameter, $\Delta y$,
- $\Delta x$ = horizontal increase in diameter due to vertical soil pressure, P,
- $D_f$ = deflection lag factor (= 1 if embedment is compacted or pipe is pressurized),
- $K_c$ = bedding factor = 0.1 (0.083 to 0.11 depending on the bedding angle),
- $W_c$ = PD = load on pipe per unit length of pipe (prismatic load),
- P = vertical soil pressure on top of the pipe,
- D = diameter of the pipe (For flexible pipe ID ≈ OD ≈ D within justifiable precision),
- r = radius (assumed equal to D/2 in the derivation of the Iowa Formula),
- E = modulus of elasticity of the pipe material,
- I = moment of inertia of the pipe wall = $t^3/12$ for plain wall pipe,
- t = wall thickness for plain pipe,
- E' = horizontal modulus of soil reaction (a modulus of elasticity — a constant),
- $\epsilon$ = vertical strain (compression) of sidefill soil due to pressure, P.

The Iowa Formula was derived to predict ring deflection. It demonstrates the importance of the soil on ring deflection. It over-predicts ring deflection because horizontal compression of sidefill soil is not uniaxial and elastic; but, rather, is a biaxial compression of particulate soil.

Vertical ring deflection, d, is of greater value for pipe design than is horizontal ring deflection. It is approximately (and conservatively) $d = \epsilon$ = vertical compression of the sidefill embedment..

The Iowa Formula for predicting ring deflection was not intended for design of the pipe. On the contrary, it shows that ring deflection is primarily a function of the soil embedment. Ring deflection caused by soil does not determine ring stiffness of the pipe. Moreover, the properties of soil are imprecise. Published USBR values of the soil modulus are, in fact, virtual E' based on back-calculations of the Iowa Formula from ring deflections of existing installations all of which disregard height of soil cover. E' is a function of height of cover; and, therefore, is not a constant for a given soil type and density as assumed in the published tables of values.. A good form for discussion of the Iowa Formula is the following,.

$$d(\%) = \frac{10P}{\underbrace{\Sigma(EI/r^3)}_{\text{PIPE}} + \underbrace{0.06E'}_{\text{SOIL}}}$$

RING DEFLECTION ..... (2)

The effects of soil and pipe are in the denominator. The following examples compare the effects on ring deflection, d, of ring stiffness, $EI/r^3$, and soil stiffness, E'. Soil stiffness is predominant.

Example 1:
A 48 inch mortar lined, tape coated, steel pipe is buried in granular embedment. In this case, ring stiffness is, conservatively the sum of ring stiffness, $\Sigma EI/r^3$, of the lining and the steel pipe. The tape coating has negligible effect on the total ring stiffness. Bond between mortar and steel is conservatively neglected. A typical value of soil stiffness is E' = 2000 psi — with height of soil cover ignored. In the denominator,

<u>PIPE</u> <u>$\Sigma EI/r^3$</u>
Steel t = 0.2 D/t = 240
$E = 30(10^6)$ psi $EI/r^3 = 1.447$ psi
Mortar t = 0.5 ID = 48
$E = 4(10^6)$ psi $EI/r^3 = 2.833$ psi
$\Sigma EI/r^3$ = <u>4.3 psi = 3 % of the denominator</u>

<u>SOIL</u> <u>0.06 E'</u> E' = 2000 psi
0.06 E' = <u>120 psi ± 12 psi stdard deviation</u>
<u>= 97 % of the denominator</u>

Clearly, the ring stiffness is negligible compared to the soil stiffness. In fact, the ring stiffness is only a third of typical standard deviation of 10 % for soil stiffness.

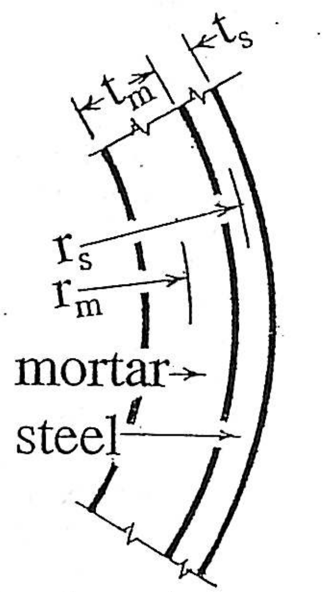


Figure 3. Section of mortar-lined steel pipe, 48 ID, D/t = 240.

Example 2:
The pipe stiffness for a PVC pipe is F/Δ = 46 psi from a parallel plate test in which F = load per unit length of pipe, and Δ = deflection of the load. F/Δ = 6.72 $EI/r^3$ from elastic analysis. Solving, $EI/r^3$ = 46/6.72 = 6.8 psi. If soil stiffness is E' = (0.06)2000 psi, ring stiffness is 5.4 % of the denominator. Ring stiffness is less than half of the standard deviation of soil stiffness.

Two conclusions are salient.
1. What is the Iowa Formula? It is an elastic model for predicting horizontal deflection of a buried flexible pipe. It is based on pipe-soil interaction. It emphasizes the importance of soil.

2. What the Iowa Formula is not? It is not a model for design of buried flexible pipes. It is not a basis for specifying ring stiffness. Ring deflection is limited by other conditions than ring stiffness of a flexible pipe. Spangler's recommended allowable ring deflection of 5 % usually covers the other conditions such as cleaning equipment and soil disturbance.

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Spangler (1941), Iowa Engineering Experiment Station, Bulletin 153.
Watkins (1958) and Spangler, Proceedings of the Highway Research Board.