You Should Know

American Concrete Pipe Association

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Don't Get Caught in Failure! Caculate E'

Based on the research article "Modulus of Soil Reaction (E'), Values for Pipeline Design" performed and written by Jey Jeyapalan, P.E. and Reynold Watkins, P.E..[1]

For years the engineering community has used oversimplified fill height tables when designing drainage pipe. This is particularly concerning in the design of flexible pipe since the majority of its structural integrity comes from the lateral support of the soil. Since this lateral support is so critical, a design parameter indicating the strength of the soil is essential. This design parameter developed by Dr. Spangler and Watkins at the Iowa State College is the soil modulus of elasticity, E'. Most fill height tables use an E' value that may not accurately correlate to the project site where the pipe will be buried. The reality is, as stated in the ASCE article, that "E' is not a fundamental geotechnical property of soil. This property cannot be measured either in the laboratory or in the field. This is an empirical soil-pipe system parameter, which could only be obtained from back-calculating by knowing the values of other parameters in the modified Iowa equation."

In 1941, Spangler realized that deflection of corrugated metal pipe was not a function of pipe strength alone, but rather the soil-pipe system. At this time the Iowa equation was derived through much research at Iowa State College. Later, in 1958, Dr. Spangler and Watkins, modified the original equation to the form below.

$$dx = DPK/(EI/r^3+0.061E')$$

where:

dx = change in the pipe's horizontal diameter
D = time lag factor
P = external earth and live loads
K = bedding constant which varies based on the bedding angle, typically 0.1
E = modulus of elasticity of the pipe material
I = moment of inertia of the pipe wall
r = mean radius of pipe
E' = modulus of soil reaction

In 1987, Hartley and Duncan proved that E' was not only varying with the soil-pipe combination, but also varied with the height of fill over the pipe. Then in 1994, Jeyapalan and Jaramillo published evidence that not only were the previously stated findings true, but E' also varied with the stiffness and the size of the pipe to be installed.

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So in 2000, Watkins produced another version of Spangler's Iowa equation to the form of:

$$dx = DP/(1.5PS+0.061E')$$

where:

PS= Pipe Stiffness

$$PS = \frac{EI}{0.149r^3}$$

Although the equation that includes E' is still the current method used today, in 1998 McGrath proposed replacing E' in the equation with a true elastic parameter, M_s, the constrained soil modulus. "This one-dimensional modulus can be determined by direct analysis from the hyperbolic soil model thus increasing stiffness with depth of fill."(2) Below is the table that McGrath suggests for the values of M_s to be used in practice. SW, ML, and CL represent well graded sand, sandy silt, and silty clay; respectively with 100, 95, 90, and 85 representing the corresponding standard proctor compaction levels. These values have been adopted by AASHTO, who also recommends designing with a compaction level 5% less than specified.

Stress Level* (kPa)	Soil type and Compaction Condition (MPa)									
	SW100	SW95	SW90	SW85	ML95	ML90	ML85	CL95	CL90	CL85
7	16.2	13.8	8.8	3.2	9.8	4.6	2.5	3.7	1.8	0.9
35	23.8	17.9	10.3	3.6	11.5	5.1	2.7	4.3	2.2	1.2
69	29.0	20.7	11.2	3.9	12.2	5.2	2.8	4.8	2.4	1.4
138	37.9	23.8	12.4	4.5	13.0	5.4	3.0	5.1	2.7	1.6
275	51.7	29.3	14.5	5.7	14.4	6.2	3.5	5.6	3.2	2.0
413	64.1	34.5	17.2	6.9	15.9	7.1	4.1	6.2	3.6	2.4

*Free Field vertical effective soil stress $\gamma_s H$
1MPa = 145 psi

In Dr. Jeyapalan and Dr. Watkins's observations they note concern over the lack of knowledge of site soil conditions and engineering design taking place when flexible pipes are specified, leading them to write their paper *Modulus of Soil Reaction (E'), Values for Pipeline Design.* Correct calculation of E' (M_s) is vital in all pipe design, but with the majority of structural strength in flexible pipe coming from the lateral pressure of the surrounding soil, it is even more critical in its design.

"Taking E' values from the design guides or simple consensus standards of the pipe vendor should be avoided. If you have never worked with E' values before, it is better you consult an expert on how to establish these values for design."

For a copy of article (1) below, please contact the ACPA.

(1)*Modulus of Soil Reaction (E'), Values for Pipeline Design* - Journal of Transportation Engineering ASCE – Jey K. Jeyapalan, P.E. and Reynold Watkins, P.E. – Jan/Feb 2004.

(2)*Thermoplastic Drainage Pipe Design and Testing – Phase 1 Interim Report* – Dr. Timothy McGrath, Dr. Benjamin W. Schafer, Dr. Ian D. Moore, and Dr. Alan J. Lesser – April 2000

