MODULUS OF SOIL REACTION, E'

The Modified Iowa Formula includes a term referred to as the modulus of soil reaction, E', and is defined as an empirical value used to express the stiffness of the embedment soil in predicting flexible pipe deflection. E' has also been referred to as the soil modulus or soil stiffness (More information on the Modified Iowa Formula can be found in Rinker Materials Info Series #204).

The U.S. Bureau of Reclamation (USBR) conducted soil tests to determine modulus of soil reaction values for a wide variety of soils having differing compaction levels. This investigation included dumped fine grain soils having high plasticity to highly compacted coarse grained materials. The results of this investigation determined **E' values varying from 0 to 3000 psi.** The USBR published these results in the 1977 report "Modulus Of Soil Reaction (E') Values For Buried Flexible Pipe". A copy of their table is included herein.

Over the years, much discussion has ensued relative to proper values of E' for the design of flexible conduits. In the original work performed by Professor Merlin G. Spangler and Dr. Reynold Watkins, an E' **value of 700 psi** was believed reasonable for typical installations. This is also the recommendation of ASCE's Manual of Engineering Practice No. 37 provided the soil is compacted to a **minimum of 90% Proctor**. The Transportation Research Board (TRB) Report 225 recommends that for shallow covers, the **listed E' value should be reduced by 50%.** ASCE's Gravity Sanitary Sewer Design and Construction Manual recommends that **75% of the listed E' values** should be used and the U.S. Soil Conservation Service applies a ϕ **factor of 0.5 to the E' values** for all fill heights.

The Engineer should note these empirical values can be affected by various factors which include soil type, soil density and moisture content. The following questions should be considered when selecting the proper E' value:

- Is a factor of safety built into the value?
- Is the value affected by the height of the overburdened soil?
- Are field tests conducted to assure such values are actually developed in the field?
- Is the relationship of the backfill material modulus to the in-situ soil modulus (combined E') being considered?

When addressing these questions and others that arise, the Engineer should be aware of several facts and concerns. One is that **the USBR table** values for E' **do not include a safety factor** and the table represents **average values only**.

Secondly, most installations have relatively little inspection and minimum, if any, ongoing field verification of soil compaction. The USBR is well known for their **rigorous inspection**, both at a manufacturing facility and in the field. Such inspection allows their values to be used with a certain degree of reliability. **Without such inspection concern relative to those values is in order.** Also, investigations subsequent to the USBR's work indicate that overburden height may change the value of E'.

The design of a flexible soil-pipe structure is highly dependent on the soil stiffness and the Engineer should familiarize himself with all the properties of the soils being used with particular attention to the E' value.

Table 1 A.

Bureau of Reclamation values of E' for Iowa formula (for initial flexible pipe deflection) (Customary units)

Soil type-pipe bedding material (Unified Classification System)[1]	E' for degree of compaction of bedding (lb/in²)			
	Dumped	Slight <85% Proctor <40% relative density	Moderate 85-95% Proctor 40-70% relative density	High >95% Proctor >70% relative density
Fine grained soils (LL>50)[2] Soils with medium to high plasticity CH, MH, CH-MH	No data available; consult a competent soils engineer; otherwise use E' = 0			
Fine-grained soils (LL<50) Soils with medium to no plasticity CL, ML, ML-CL, with less than 25 percent coarse-grained particles	50	200	400	1000
Fine-grained soils (LL<50) Soils with medium to no plasticity CL, ML, ML-CL, with more than 25 Percent coarse-grained particles Coarse-grained soils with fines GM, GC, SM, SC[3] contains more than 12 percent fines	100	400	1000	2000
Coarse-grained soils with little or no fines GW, GP, SW, SP[3] contains less than 12 percent fines	200	1000	2000	3000
Crushed rock	1000	3000		
Accuracy in terms of percent deflection[4]	±2%	±2%	±1%	±0.5%

[1] ASTM Designation D 2487, USBR Designation E-3.

[2] LL = liquid limit.

[3] Or any borderline soil beginning with one of these symbols (i.e., GM-GC-SC).

[4] For ± 1 percent accuracy and predicted deflection of 3 percent, actual deflection would be between 2 % and 4 %.

Note:

A. Values applicable only for fills less than 50 ft.
B. Table does not include any safety factor.
C. For use in predicting initial deflections only, appropriate deflection lag factor must be applied for long-term deflections.
D. If bedding falls on the borderline between two compaction categories, select lower E' value or average the two values.
E. Percent Proctor based on laboratory maximum dry density from test standards using about 12 500 ft-lb/ft³ (ASTM D-698, AASHTO T-99, USBR Designation E-11).