Modulus of Subgrade Reaction for Storage Racking on Slabs-on-Ground Made Easy

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In our previous Engineering Bulletin "Modulus of Subgrade Reaction – Which One Should be Used?" (Ref.1), we provided background information on the different modulus of subgrade values and provided values based on the different soil types. As discussed in the previous Engineering Bulletin, the slab stress analysis is not sensitive to the value of the subgrade reaction, and therefore selecting a modulus of subgrade reaction based on soil type is often satisfactory. However, in this Engineering Bulletin we will provide a more definitive method of determining the modulus of subgrade reaction based on the slab's settlement due to the racking load. This definitive method uses the method as discussed in our previous Engineering Bulletin where we find the equivalent modulus of subgrade reaction that provides the same moment in the slab as the solid finite element model that matches the long-term total settlement provided by the geotechnical engineer.

Assumptions used

As discussed previously, slab stress analysis is not sensitive to the value of the subgrade reaction, and therefore only a reasonably close rack loading is needed to determine the modulus of subgrade reaction. We have chosen the loading shown below in Fig. 1. The racking is a nominal 4 ft. x 8 ft. with a 1 ft. flue, which is fairly common for wide aisle warehouse racking. We have used a post load of 9,000 lbs. on a 4 in. square baseplate and a 7" slab. However, the modulus of subgrade reaction using this method should be sufficient for 6" to 9" slab thickness, and settlements should not exceed much over 1" for good warehouse racking operations.

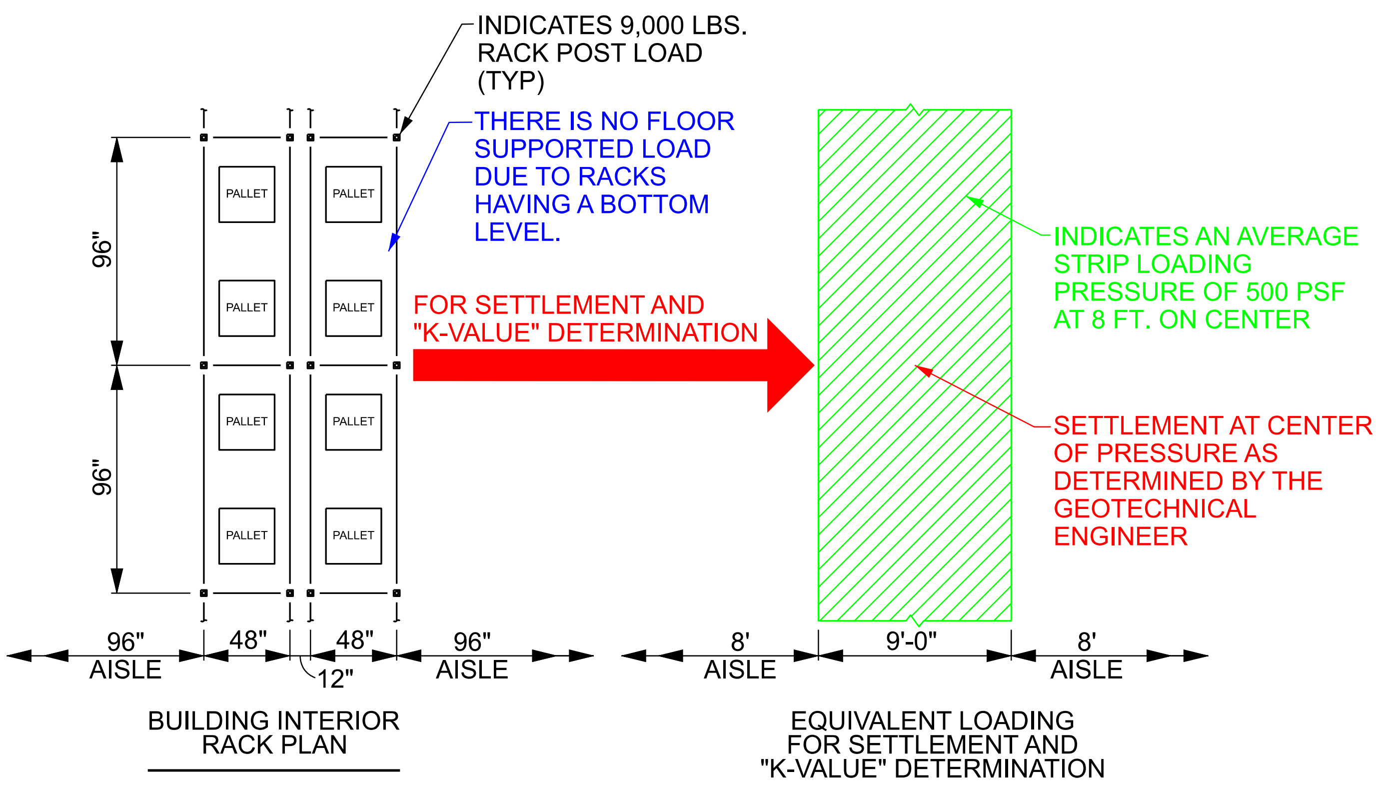
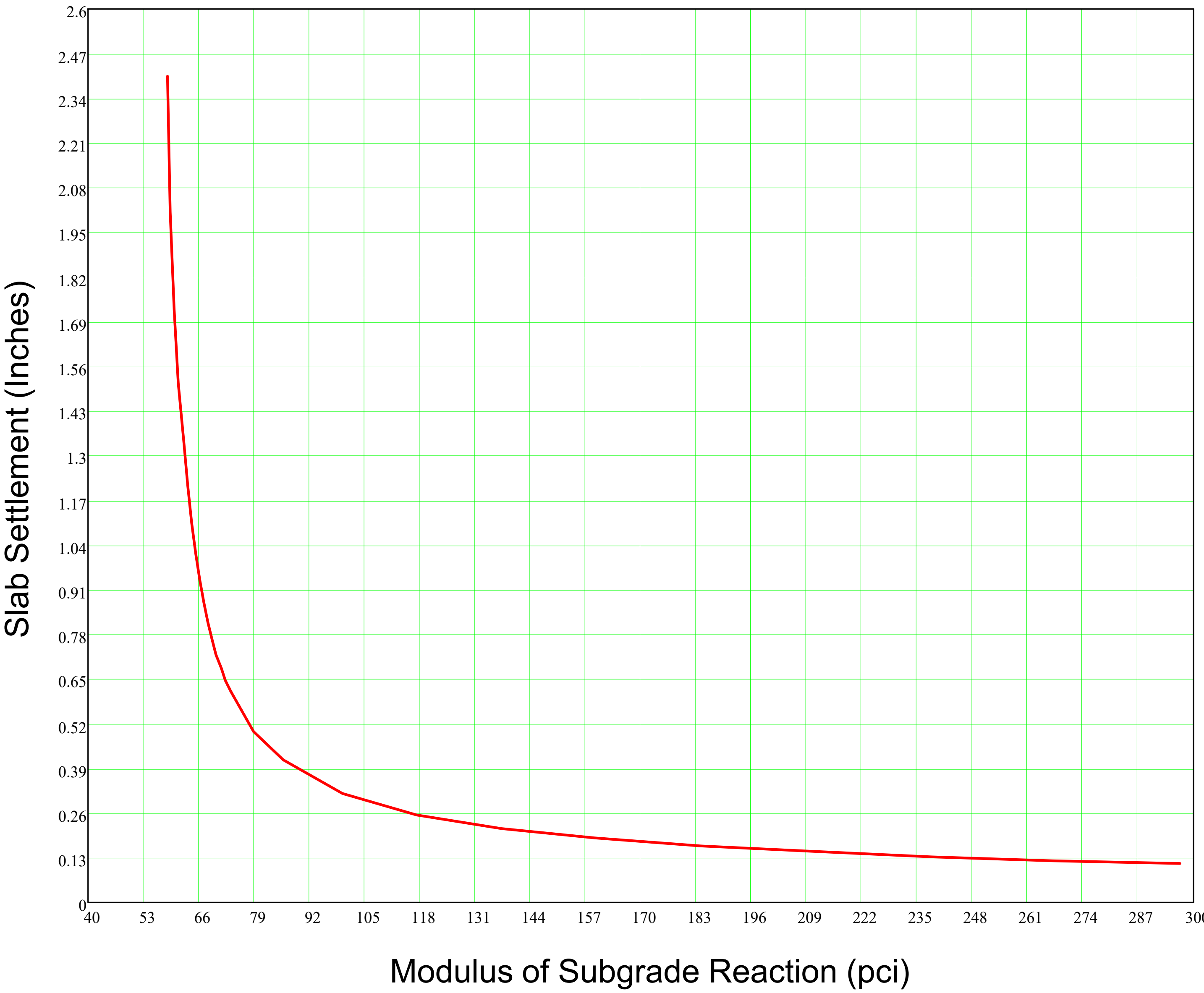


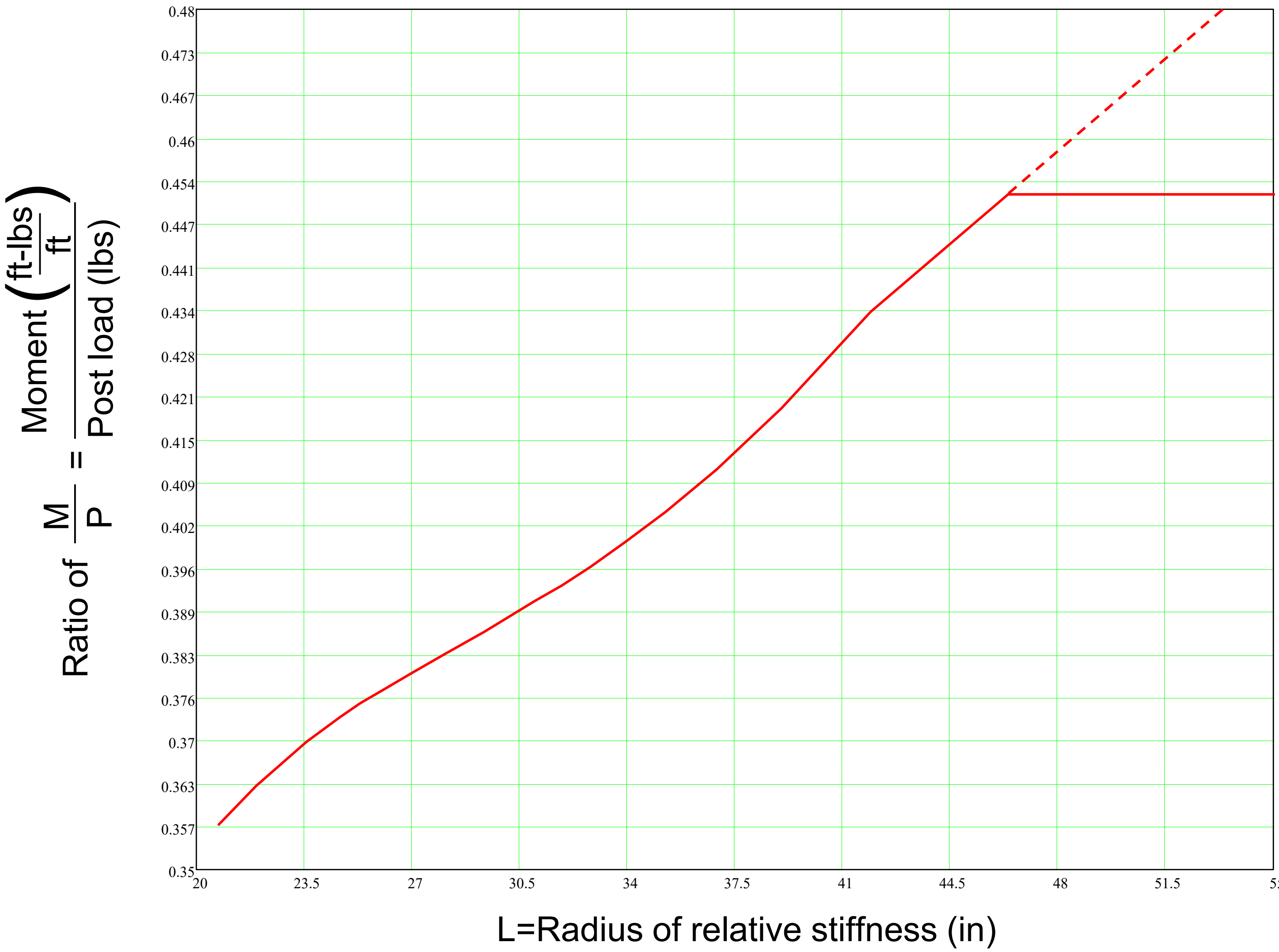
Fig. 1 Racking equivalent uniform loading to determine settlements

Once the geotechnical engineer has determined the settlement at the center of the pressure, Fig. 2 can be used to determine the modulus of subgrade reaction. Note as the modulus of subgrade reaction become less than about 66 pci for this racking geometry, then the slab settlements become excessively high. This is because the modulus of subgrade reaction method cannot converge to a rigid foundation (the springs are uncoupled as discussed in our previous Engineering Bulletin) where the slab is now very stiff compared to the soil and the soil pressure will be nearly uniform.



<u>Fig. 2 Slab settlement versus modulus of subgrade reaction</u>

As shown below in Fig. 3, as the ratio of the moment/post load reaches 0.45, then the maximum moment is reached as the moment in the slab cannot be higher than a uniform pressure under the slab. Unfortunately, we have seen where low modulus of subgrade reaction values were used and moments much higher than produced by a uniform pressure under the slab were used to design the slab (red dashed line in Fig. 3).



<u>Fig. 3 Ratio of M/P versus radius of relative stiffness</u>

The method will be demonstrated by an example.

Example

Determine the modulus of subgrade reaction and the moment in a 6” slab with a 7,000 lbs. post load.

The geotechnical engineer determined the long-term settlement at the center of the pressure as shown below in Fig. 4 to be 0.5”. From Fig. 2, the modulus of subgrade reaction would be 78 pci.

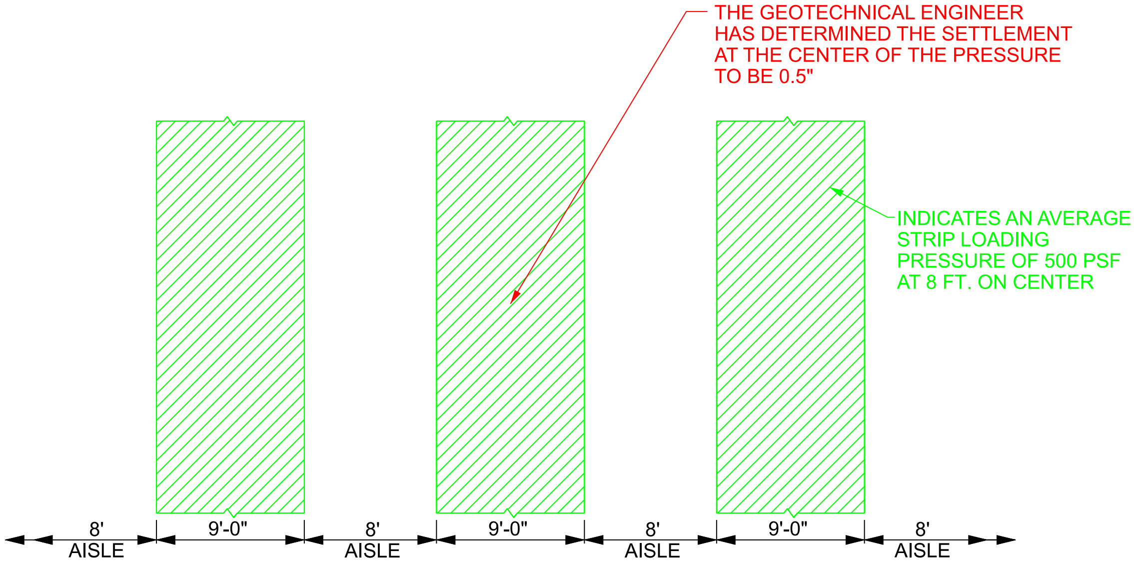


Fig. 4 Racking settlement as determined by the geotechnical engineer

The moment in the slab is determined using Fig. 3. The equations are as follows:

$$D = \frac{E_c t^3}{12(1-\mu^2)}$$

$$L = \sqrt[4]{\frac{D}{k}}$$

Where:

D = Slab’s flexural rigidity (lbs.-in)
E_c = Concrete elastic modulus (psi), approximately 3,605,000 psi for concrete with a compressive strength of 4,000 psi.
t = slab thickness (in)
μ = Poisson’s ratio, approximately 0.15
L = Radius of relative stiffness (in)
K = Modulus of subgrade reaction (pci)

$$D = \frac{3{,}605{,}000\ psi(6in)^3}{12(1-0.15^2)} = 66{,}384{,}000\ lbs - in$$

$$L = \sqrt[4]{\frac{66{,}384{,}000\ lbs - in}{78\ pci}} = 30.3\ in$$

From Fig. 3, the ratio $\frac{M}{P} = 0.39$. The moment in the slab would be 0.39(7,000 lbs) = 2,730 ft-lbs/ft.

References:

1. Walker, W.W., and Holland, J.A., “Modulus of Subgrade Reaction – Which One Should be Used?”, Engineering Bulletin, Structural Services, Inc., 11 pp., http://www.ssiteam.com/publications .

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