DRILLED SHAFTS – EQUIVALENT POINT OF FIXITY

IF THERE WAS EVER A TOPIC REQUIRING COMMUNICATION BETWEEN STRUCTURAL AND GEOTECHNICAL ENGINEERS – THIS IS IT!

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If the geotechnical engineer applies vertical and lateral loadings to a drilled shaft that is adequately stiff structurally and doesn't deflect excessively due to soil-structure interaction why does he or she need to worry about or ever consider the drilled shaft's "fixity" or "equivalent point of fixity"? The answer is simple…he doesn't.

If the structural engineer assumes that the end of his or her column is fixed at some point in the ground, runs a structural model based on this assumption for his or her bridge, and the actual stiffness generated by the shaft in the ground matches the stiffness generated by foundation assumptions used in his or her model, then why does the structural engineer need to consider "geotechnical fixity" or the "equivalent point of fixity"? Again the simple answer is that he doesn't.

If the geotechnical and structural engineers could work without interacting, there would not be the need for considering shaft fixity. And there you have it, the 800 pound gorilla in the room! Geotechnical and structural engineers do have to work together to design bridge super-structures and to design bridge foundations. The concept of drilled shaft fixity is the tool or language if you will that allows geotechnical and structural engineers to communicate.

How does the tool of "fixity" work? The simple answer is that fixity is used to communicate the stiffness of the soil-foundation system for use in the bridge structural analysis program and in the foundation analysis program which is commonly LPile.

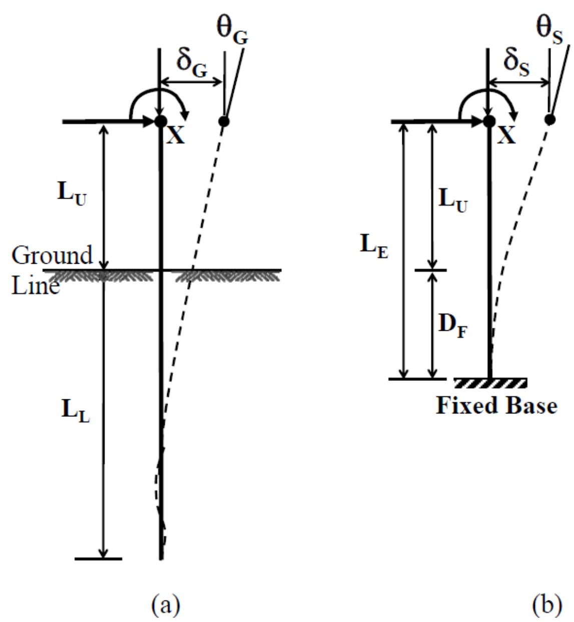
To analyze a structural frame, the analyst has to input loads at nodes or members, and they have to input parameters into the program that allow it to calculate the axial, torsional and bending stiffness of each member and generate a stiffness matrix for the structure. Outputs of the structural analysis program are vertical deflections, lateral deflections and angular twists. Of course the program can also calculate shears, moments, and torques from analysis of the applied loads to the structure. Everything would be great for the structural engineer so long as he or she could rigidly bolt the base of each column to solid granite bedrock.

Of course all bridges are not built on shallow exposed granite bedrock, sometimes, even most of the time, we have to found bridge columns and abutments on drilled shafts socketed into native soils. When bridge columns are supported on drilled shafts socketed into native soils, we don't have a pinned end nor a fixed end condition at the base connection between the column and the drilled shaft. The actual column-shaft connection moves vertically, laterally and twists by amounts that are indeterminate such that the structural engineer cannot input stiffness values that are useable by his or her computer model. What to do?

The answer is to make an assumption and check the assumption. If the assumed value closely matches the calculated value then the assumption is assumed to be OK, if it does not, we have to adjust the assumption and re-analyze the structure. A process that is commonly called “trial and error”.

At this point, we need to understand that a simplified structure’s stiffness can never (or nearly never) completely match the stiffness of the actual (complicated) structure. It is up to the designer to decide what parameter or parameters to select for comparing model and actual structure stiffness. When designing bridge foundation drilled piers, I select the lateral defection at the top of the drilled shaft to match bridge column lateral deflection at the column to shaft connection. Sometimes the bridge designer requests that we match the lateral deflection at the top of the bridge column, or infrequently they ask that the two models match both lateral deflection and rotation at the top of the bridge column. Matching one parameter by use of the trial and error method works quite well, matching two parameters does not work as well because as I mentioned above the stiffnesses of the simplified and the actual model do not completely match.

I must again complement the engineers at the Arizona Department of Transportation’s Geotechnical Design Section (I complemented ADOT several times in my latest book, Lommler 2012). In their Geotechnical Design Policy DS-3, December 1st 2010, in Section III, “Depth to Fixity, D_F”, they do a good job of describing the depth to fixity as a modeling parameter that is used in a “trial and error” approach to work with the bridge structural engineer. The figure below is from ADOT’s DS-3. Figure (a) is the geotechnical model and Figure (b) is a portion of the structural model (i.e. the rest of the bridge structural frame is not shown):



Note that ADOT is asking the structural and geotechnical engineers to match both deflections and rotations at a point on the column to within 10% of each other. I believe this is ADOT’s concession that these two models’ stiffness matrices do not match.

Use of the equivalent point of fixity discussed above is for the analysis of laterally loaded piles and drilled shafts. In AASHTO section 10.7.3.13.4, “Buckling and Lateral Stability”, a completely different topic is being discussed. Section 10.7.3.13.4 is referring to buckling of axially loaded columns; in this case the columns are piles. Lateral loading of piles is not involved in this discussion. The term laterally unsupported length in 10.7.3.13.4 is referring to the buckling length of an axially loaded column. If one recalls their class work in structural engineering a column pinned at each end has a physical length equal to the buckling length, and the K factor is equal to 1.0. If a column is pinned at one end and fixed at the other, its buckled length is twice its physical length, and it has a K factor of 2.0.

Buckling of columns is a rather complicated topic and is currently a subject of debate amongst structural engineers. It is not AASHTO’s intention to make bridge structural design more complicated than necessary for bridge design engineers, so they have again simplified the portion of a pile that extends into the ground for buckling analyses and used the concept of depth to fixity, D_F. Since this use of depth to fixity is intended for a different purpose than the laterally loaded pile’s depth of fixity discussed above, I have noted that geotechnical engineers are quite often confused by the double use of this term. I suggest that they be considered separately for use when analyzing laterally loaded piles or when analyzing axially loaded piles for buckling. I consider this confusion of terms to be like the English language where one often never knows what a word means without first considering its context.

John Lommler, September 9, 2012