

TECHNICAL NOTE NO. 1.6.3

Determination of Downdrag Loads for Rigid Inclusion Design

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Downdrag, or reverse skin friction, occurs when soil moves down relative to a rigid inclusion element. This Technical Note reviews the mechanisms of downdrag, presents guidance on when to include downdrag loads, and provides several methods for calculating and applying downdrag loads in design.

Downdrag Mechanisms

Downdrag, or reverse skin friction, occurs when there is a relative movement of soil downward with respect to a rigid inclusion element. The soil moving downward relative to the RI imparts additional load on the element that can result in additional settlement and increased axial stresses. This is shown in Figure 1.6.4-1, below.

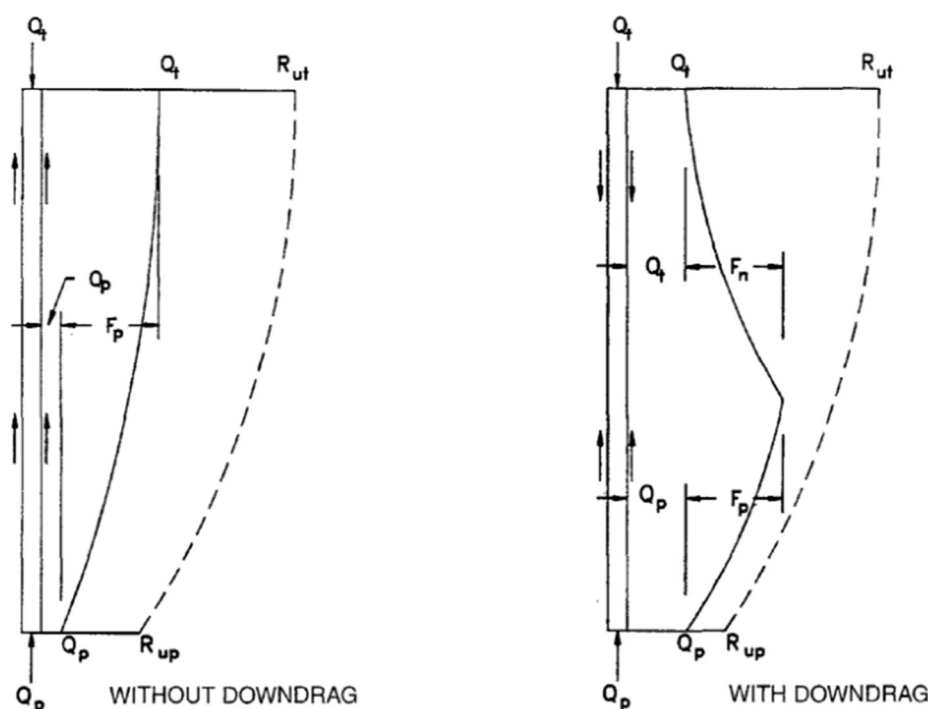


Figure 1.6.4-1 Downdrag effects on rigid elements (Briaud and Tucker 1997).

The relative movement can be caused by several mechanisms:

- When RIs are installed through fine grained material that has not finished consolidating. Several situations can cause this:

- An under-consolidated profile. These are geologically unique and typically result from recent lowering of groundwater levels.
- Fill placement above fine-grained soils. If the soil is not allowed to finish consolidating from the fill placement prior to the installation of rigid inclusions, the additional fill will induce downdrag loads.
- Secondary compression of thick organics and/or landfill material
- Liquefaction-induced settlement

Because the most common instance of downdrag loads come from the addition of fill, it is important to recognize that it is mechanically impossible to have a downdrag load greater than the amount of additional load applied. This is because once the forces resisting downdrag (which is the “upward” resistance from the RI elements) equal the forces inducing downdrag loads (the additional load), there is force equilibrium and movement stops.

In situations where the soil is under-consolidated, or will experience significant secondary consolidation (the second case discussed above), the self-weight of the material imposes the downdrag load. In these situations the downdrag load must be considered, but there are other design issues that must be addressed. **Refer to TN 1.6.4 for the correct design approach in these soils.**

It is also important to recognize that any additional areal loading after RI installation, such as additional fill placement or slab/mat loading, is capable of inducing downdrag loads. However, Geopier’s approach in these situations is to account for the portion of the load that will be attracted to the RI elements, and therefore downdrag is inherently accounted for.

Calculating Downdrag

There are several methods to calculate downdrag loads. In general, the more conservative methods are quick and simple whereas the more precise methods take longer to calculate.

Method 1

The most conservative and simplest method is to account for all load that is inducing downdrag in the loads to be resisted by the elements. Add the tributary soil load to each footing that must be resisted by the piers supporting the footing, and to each slab pier.

Method 2

Calculate downdrag loading in the traditional way by determining the amount of skin friction that will be applied to the element above the neutral plane. We recommend using the skin friction calculations provided in TN 1.6.2. Downdrag occurs as the compressible

layer consolidates, which is a drained process. Therefore only drained skin friction values need to be calculated.

Downdrag loads applied through skin friction will be applied on the RI to a depth at which the movement of the element is equal to the settlement of the soil. This is referred to as the neutral plane, and is shown conceptually in Figure 1.6.4-2. It is conservative to use the bottom of the compressible layer as the neutral plane and thus consider skin friction of all layers above as contributing to downdrag.

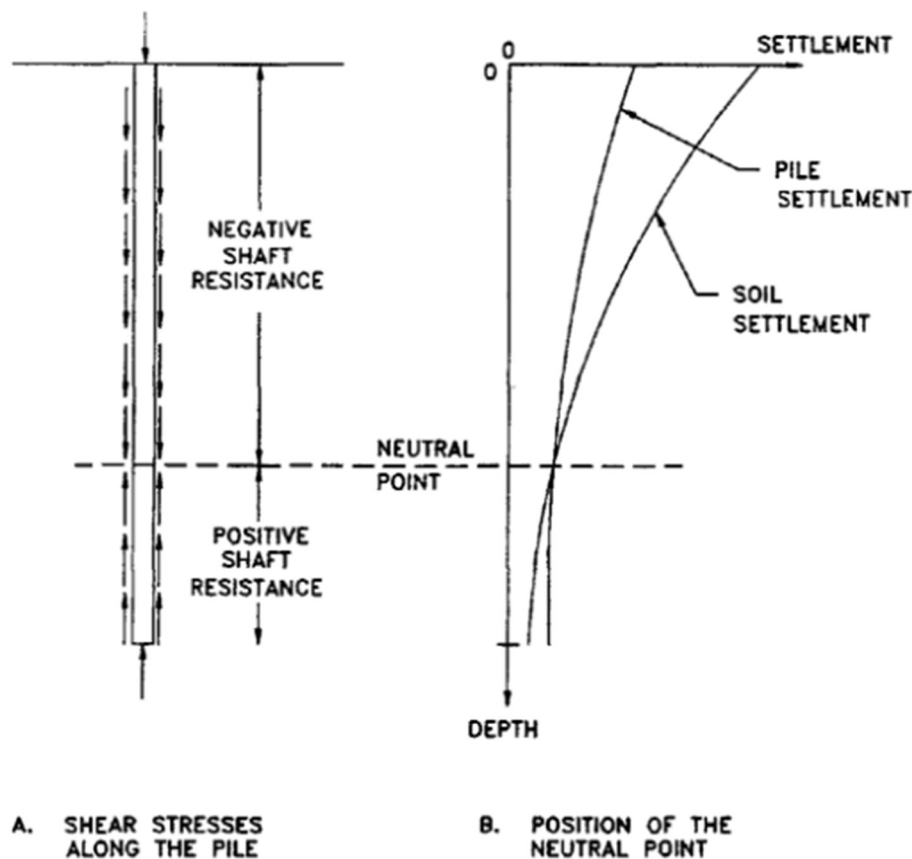


Figure 1.6.4-2. Neutral plane location (Briaud and Tucker 1997).

After calculating the downdrag load using this method, compare it to the load that would be calculated using Method 1 as Method 1 is an upper bound. If the load is greater than what is determined using Method 1 it means the neutral plane is too deep and the downdrag load should be limited to that calculated using Method 1.

Applying Method 2 Downdrag Loads to Footings

When applying Method 2 loads to piers supporting footings, the designer often need not consider the entire RI perimeter as susceptible to downdrag loads. Briaud and Tucker

(1997) provide downdrag reduction factors for pile groups relative to the pile's location in the group. These reduction factors can be applied to RI groups supporting footings. The reduction factor is a function of RI-to-RI spacing and diameter. For spacing/diameter ratios between 5 and 2.5, the designer should interpolate.

$$S/D = 5$$

$$F_{n(\text{corner})} = 0.9 F_{n(\text{single})}$$

$$F_{n(\text{side})} = 0.8 F_{n(\text{single})}$$

$$F_{n(\text{interior})} = 0.5 F_{n(\text{single})}$$

$$S/D = 2.5$$

$$F_{n(\text{corner})} = 0.5 F_{n(\text{single})}$$

$$F_{n(\text{side})} = 0.4 F_{n(\text{single})}$$

$$F_{n(\text{interior})} = 0.15 F_{n(\text{single})}$$

- S** = center-to-center spacing
D = pile diameter
 $F_{n(\text{single})}$ = downdrag force on the single pile
 $F_{n(\text{corner})}$ = downdrag force on a corner pile in the group
 $F_{n(\text{side})}$ = downdrag force on a side pile in the group
 $F_{n(\text{interior})}$ = downdrag force on an interior pile in the group

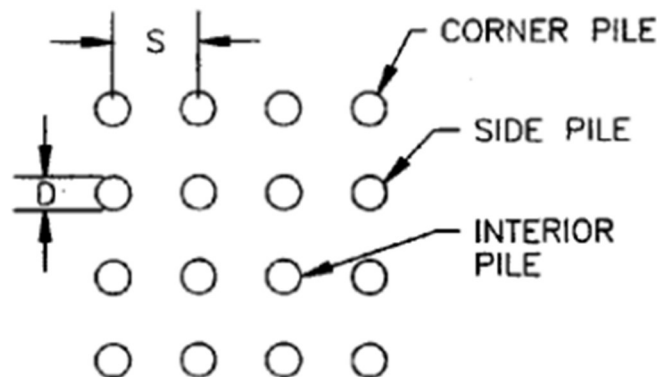


Figure 1.6.4-3. Reduction Factors for RI Groups (Briaud and Tucker 1997).

In addition to the reduction factors, consider the following cases:

- A reduction factor of 0 may be used for interior piers if:

- There is no new fill leading to unrealized consolidation below bottom of footing, and;
- The weight of all fill above the footing is accounted for as a load to be resisted.

In this case, downdrag will result from the unsupported fill around the footing consolidating the underlying layers and therefore only subjecting the perimeter piers to downdrag loads.

- Use the interior reduction factor from Figure 1.6.4-3 if there is new fill leading to unrealized consolidation below bottom of footing.

Additional Considerations

Incorporating Downdrag Loads in Settlement and Capacity Calculations

Settlement: Because downdrag induces loads that contribute to settlement during the life of the structure, they should be considered in the settlement calculations to meet serviceability criteria.

Structural RI Capacity: Downdrag induces additional load on the element and thus should be included as a factored load (LRFD) or unfactored load (ASD) in determining acceptability of the factored structural resistance of the rigid inclusion (LRFD) or factor of safety of the structural resistance (ASD) (Siegel et al. 2013).

Geotechnical RI Capacity: The ultimate geotechnical capacity should be considered without the influence of downdrag load. The geotechnical capacity should not be reduced by the anticipated downdrag load nor should only the capacity below the neutral plane be considered because at the ultimate limit state, all side resistance is positive (Siegel et al. 2013).

Organic Soil Properties

Because organic soil layers can contribute to downdrag, guidance on determining the lateral earth pressure coefficient is provided in Figure 1.6.4-4, and guidance on determining the drained friction angle is provided in Figure 1.6.4-5. Both figures are from Edil and Wang (1999).

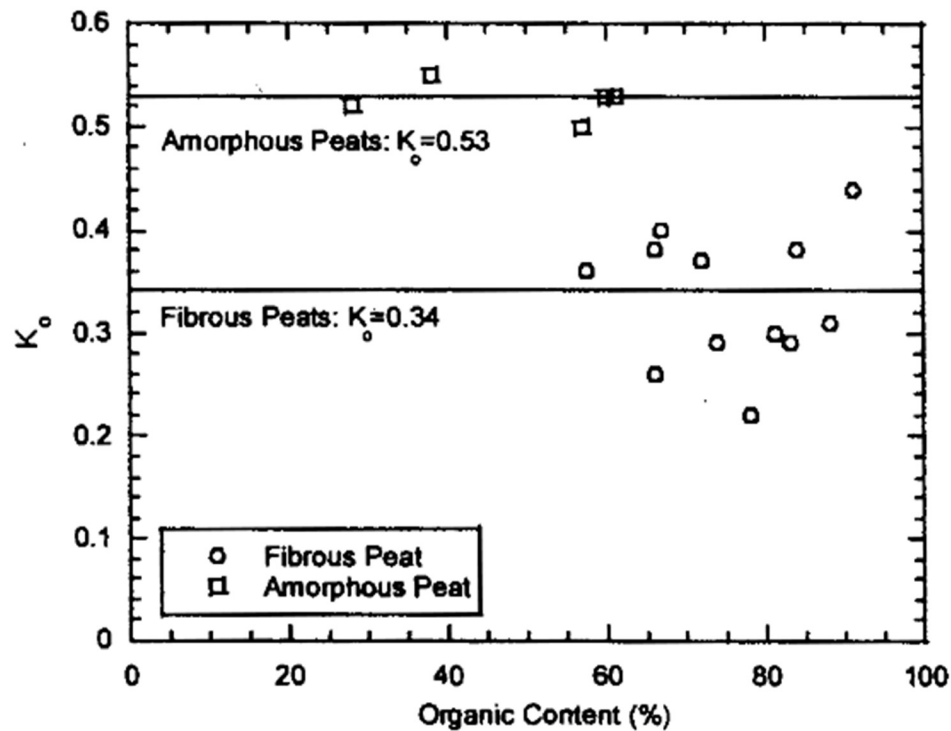
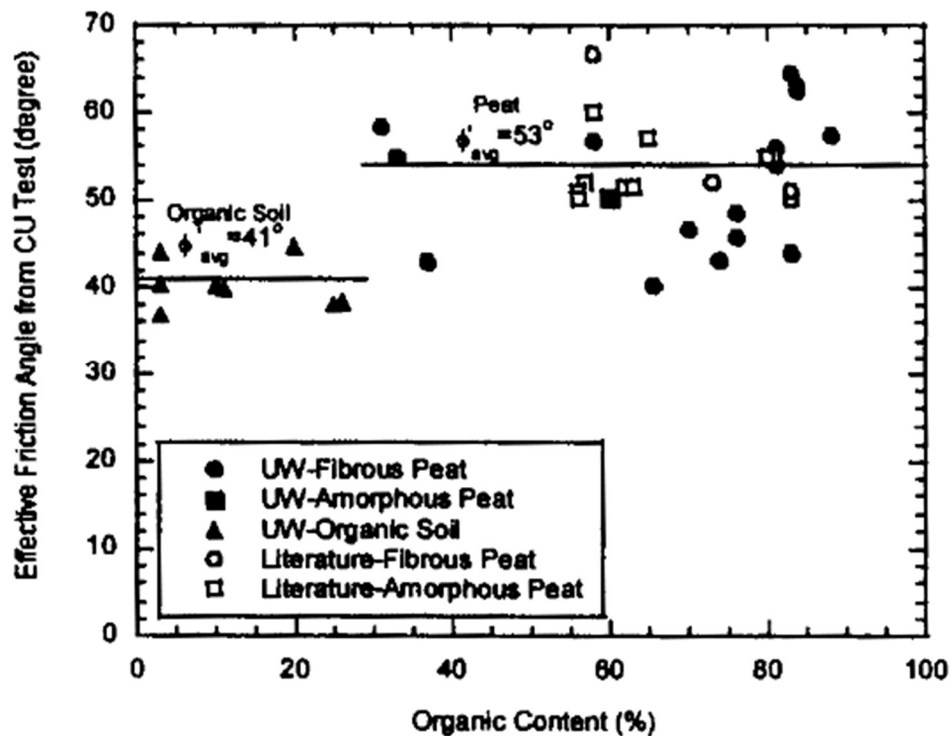
Figure 1.6.4-4. K_o versus Organic Content

Figure 1.6.4-5. Effective Friction Angle versus Organic Content.

Downdrag Loads from Liquefaction

Liquefaction may induce downdrag loads. The shear strength of liquefiable soils is very low during liquefaction and downdrag from liquefiable layers can generally be neglected or conservatively calculated using a lateral earth pressure coefficient of 1 and shear strength of 10% of the vertical effective stress. Typical downdrag procedures apply to any non-liquefiable layer above a liquefiable layer in which settlement is expected.

Because liquefaction exists during earthquakes, which is generally not considered a serviceability event, careful consideration must be given as to the appropriate application of loads. Unless it is a critical structure and/or the Owner or design team specifies otherwise, liquefaction-induced downdrag should be considered according to life-safety criteria (please refer to ASCE 7-16 Section 12.3 for these criteria).

Slab Support Conditions

The slab support condition is independent of using Method 1 or Method 2 in determining the downdrag load. For example, if Method 1 is used and all the tributary fill load is assumed to be supported by the RI, it does not mean a uniform support condition exists under the slab.

In the case of downdrag, the support of the slab should be evaluated in accordance with TN 5.6.1 considering 100% of the cone load is supported by the rigid inclusion ($k_m = 0$ pci approach).

Footing-Only Support

Downdrag loads must be carefully considered in situations where Geopier is only being asked to support the footings but where downdrag will occur. Beyond the differential settlement between the rigid inclusion-support footing and the unsupported slab which must be excluded from our scope, downdrag load will act on the RIs supporting the footings. This is especially important if Method 1 is generally used to calculate downdrag loads because, depending on the spacing, the slab piers likely support some of the tributary load contributing to downdrag at the footing locations. The unsupported slab load will also induce downdrag. For these reasons, Method 2 is recommended when footing-only support conditions are present.

References

Briaud, J.L. and L. Tucker. 1997. "Design and Construction Guidelines for Downdrag on Uncoated and Bitumen-Coated Piles". NCHRP Report 393. Transportation Research Board. Washington, D.C.

Edil, T.B. and X. Wang. 1999. "Shear Strength and K_o of Peats and Organic Soils". ASTM Special Technical Publication. 209-225.

Siegel, T.C., Lamb, R., Dasenbrock, D., and P.J. Axtell. 2013. "Alternative Design Approach for Drag Load and Downdrag of Deep Foundations within the LRFD Framework". Deep Foundations Institute. 23-39.