Downdrag in Foundation Design

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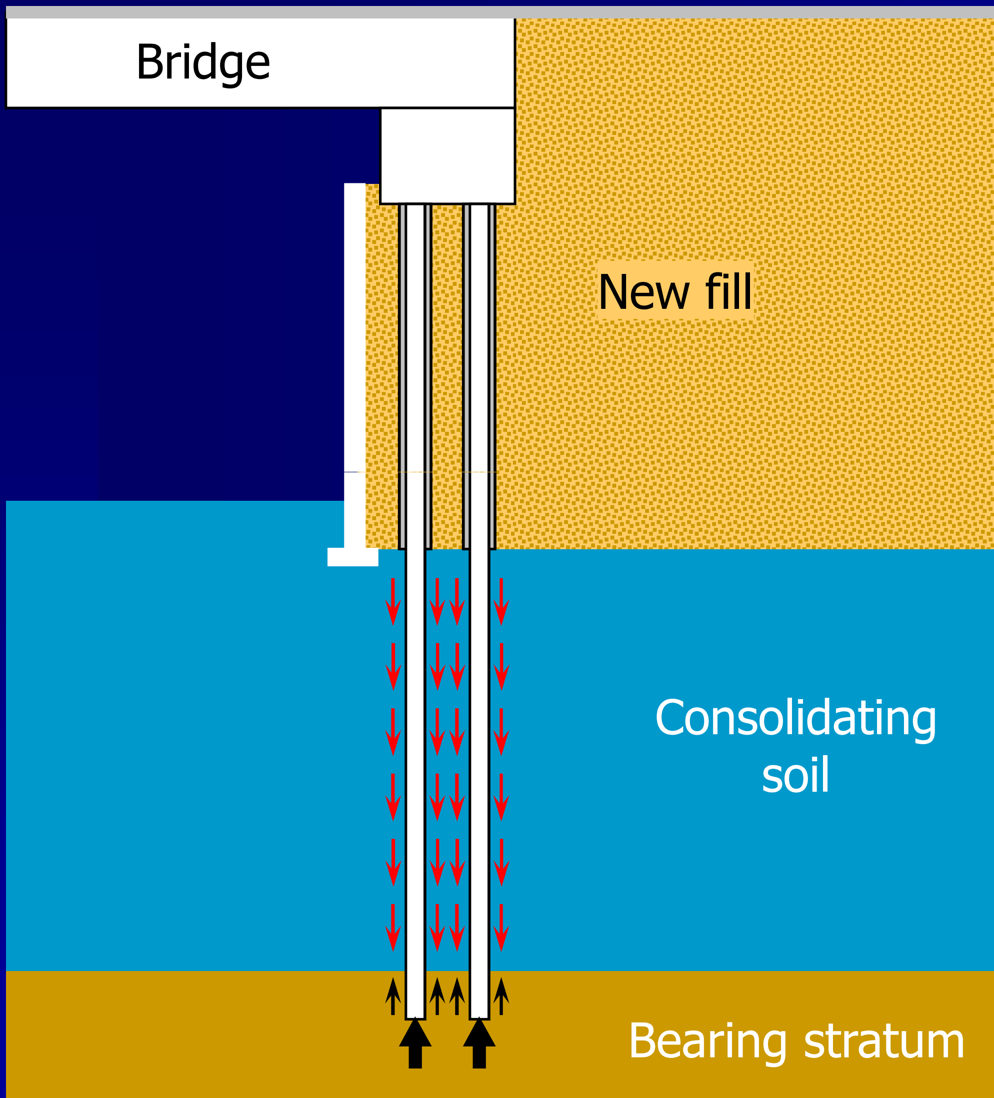
What is downdrag?

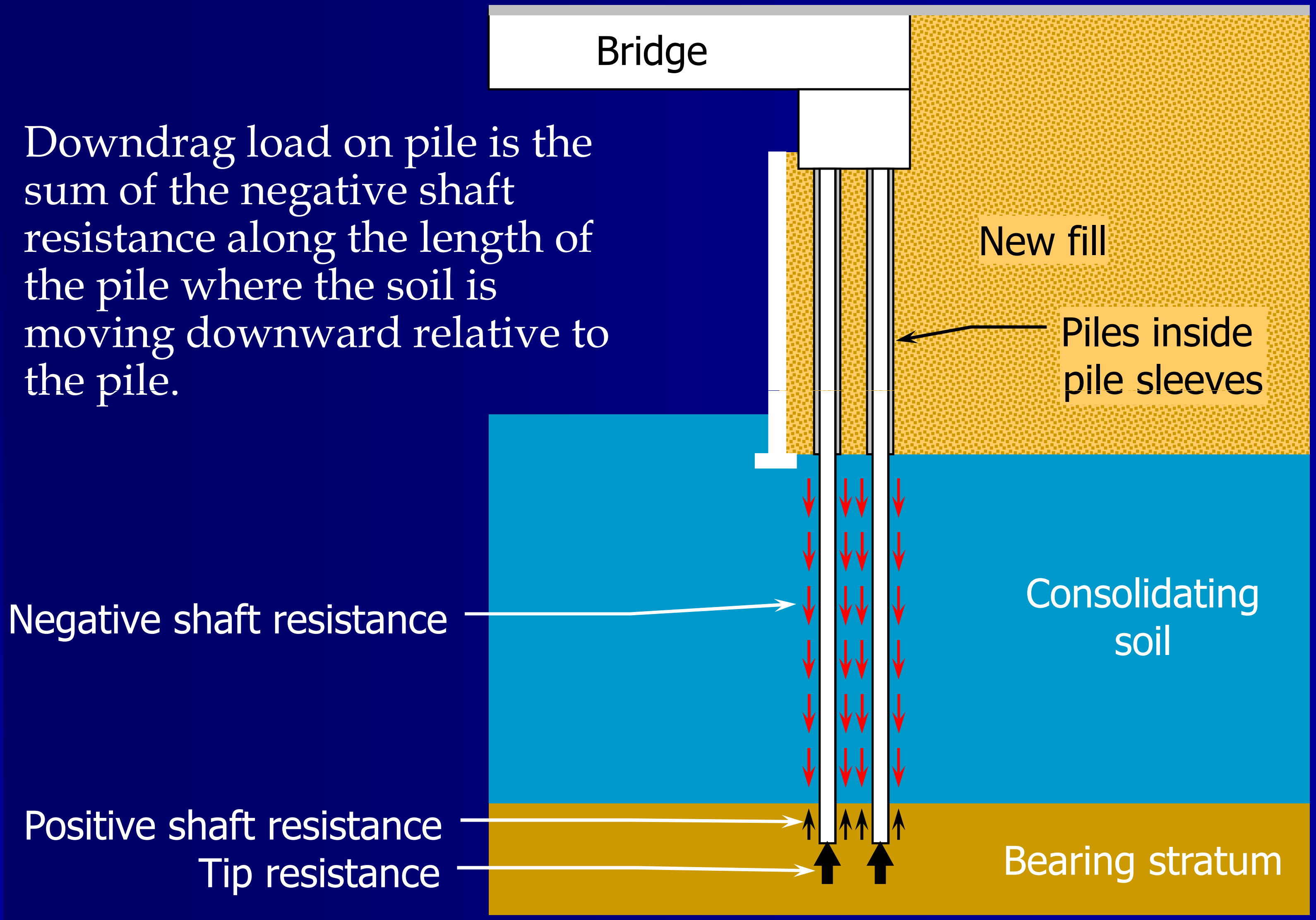


Settlement of soil after piles are driven applies additional loads to the pile.

The additional load is caused by the friction or adhesion between the pile and the downward moving soil.

What is downdrag?

Downdrag load on pile is the sum of the negative shaft resistance along the length of the pile where the soil is moving downward relative to the pile.



Terminology

AASHTO LRFD Specifications
- Downdrag or downdrag load
- Negative skin friction, negative skin resistance
- Settlement of the pile due to downdrag

Design & Construction of Driven Pile Foundations, FHWA
- Downdrag forces or dragload
- Negative shaft resistance

Fellenius, et al.
- Dragload
- Negative skin friction or negative shaft friction
- Downdrag (refers only to settlement of the pile)

Analysis methods for downdrag

Traditional Method

- Presented in *Design & Construction of Driven Pile Foundations (1996)*, FHWA, and in AASHTO LRFD Specification

Neutral Plane Analysis

- Presented by Briaud & Tucker (1997) in NCHRP Report 393
- Presented as an alternative to the Traditional Method in *Design & Construction of Driven Pile Foundations* (2006), FHWA, and by Christopher Dumas (2000)
- Allowed by the AASHTO LRFD Specification

Traditional Method (Allowable Stress Design)

- Calculate consolidation settlement for the soil layers along the length of the pile.
- Determine the length of the pile that will experience negative shaft resistance, based on a settlement criteria of 0.4 inch.
- Calculate negative shaft resistance using the same methods to calculate positive shaft resistance.
- Calculate ultimate pile capacity provided by positive shaft resistance and tip resistance.
- Determine net ultimate pile capacity by subtracting negative shaft resistance from ultimate pile capacity.

$$Q_{net} = Q_{ult}^{+} - Q_{s}^{-} \geq FS\ (DL+LL)$$

Traditional Method

- Assumes soil settlement greater than 0.4 inch will cause negative shaft resistance and soil settlement less than 0.4 inch will provide positive shaft resistance.
- Does not explicitly consider settlement or elastic compression of the pile under applied loads.
- Considers application of transient loads (live load) concurrently with permanent loads (dead load).

Neutral Plane Analysis

- Transient loads (live loads) cannot act in combination with permanent loads (dead loads).
- Explicitly consider settlement and elastic compression of the pile under applied loads.
- Assumes any downward movement of soil relative to the pile will cause negative shaft resistance.

Neutral Plane Analysis (Allowable Stress Design)

- Determine dead load (DL) and live load (LL) for pile.
- Assume an initial neutral plane at the top of the soil layer with near zero settlement.
- Calculate negative shaft resistance for soils above neutral plane, Q_s^-, and check the allowable structural capacity of the pile.

$$Q_{all\ str} \geq \text{the greater of the following:}$$

$$DL + LL \quad \text{or} \quad DL + Q_s^-$$

Neutral Plane Analysis (Allowable Stress Design)

- Determine if live load or downdrag will control the required ultimate soil resistance. For live load to control, it must be greater than the negative shaft friction plus the added positive shaft friction provided by the soils as the neutral plane moves upward under the application of the live load.
- Since the negative and positive shaft friction are equal in magnitude, the ultimate live load must be greater than twice the downdrag load to control the required ultimate soil resistance.

$$\text{If } LL \cdot FS < 2\,Q_s^- \text{ then}$$

$$Q_{req\ ult} = DL \cdot FS + Q_s^-$$

$$\text{Else, } Q_{req\ ult} = (DL+LL) \cdot FS$$

- Refine location of neutral plane by calculating pile settlement and elastic shortening due to application of $Q_{req\ ult}$ and comparing to calculated soil settlement.

AASHTO LRFD

Downdrag is always treated as a load, DD.

The load factor, γ_p, for downdrag is dependent on the method used to calculate the downdrag load.

Transient loads may or may not be considered concurrently with permanent loads.
(See Section 3.11.8 and commentary)

AASHTO LRFD

	Method for estimating downdrag [1]	Load factor γ_p for DD [2]
Piles		
cohesive soil	α (total stress) or	1.4
	λ (effective stress)	1.05
	as an alternative, β (effective stress) may be used for long-term conditions	*
cohesionless soil	Effective stress method	*
Drilled shafts		
cohesive soil	α (total stress)	1.25
granular soil	β (effective stress)	1.25

* Load factor not given

[1] Recommended method in AASHTO LRFD C3.11.8

[2] AASHTO LRFD Table 3.4.1-2

AASHTO LRFD
Piles driven to refusal on bedrock

Structural resistance controls and factored structural resistance must be greater than factored loads.

AASHTO LRFD

$$P_r = \phi_c P_n \qquad \text{Eq. 6.9.2.1-1}$$

$$P_n = F_y A_s \qquad \text{Eq. 6.9.4.1-1}$$

$$P_r = 0.5 F_y A_s$$

for H-piles with severe driving conditions

AASHTO LRFD
Piles driven to refusal on bedrock

Traditional Method

$P_r \geq \Sigma\gamma_i Q_i + \gamma_p DD$ with permanent & transient loads

Neutral Plane Analysis

$P_r \geq \Sigma\gamma_i Q_i + \gamma_p DD$ with permanent loads only

and

$P_r \geq \Sigma\gamma_i Q_i$ with permanent & transient loads (no downdrag)

AASHTO LRFD
Piles not driven to refusal

Geotechnical resistance probably controls and nominal driving resistance must include downdrag load and initial positive shaft resistance in the downdrag zone.

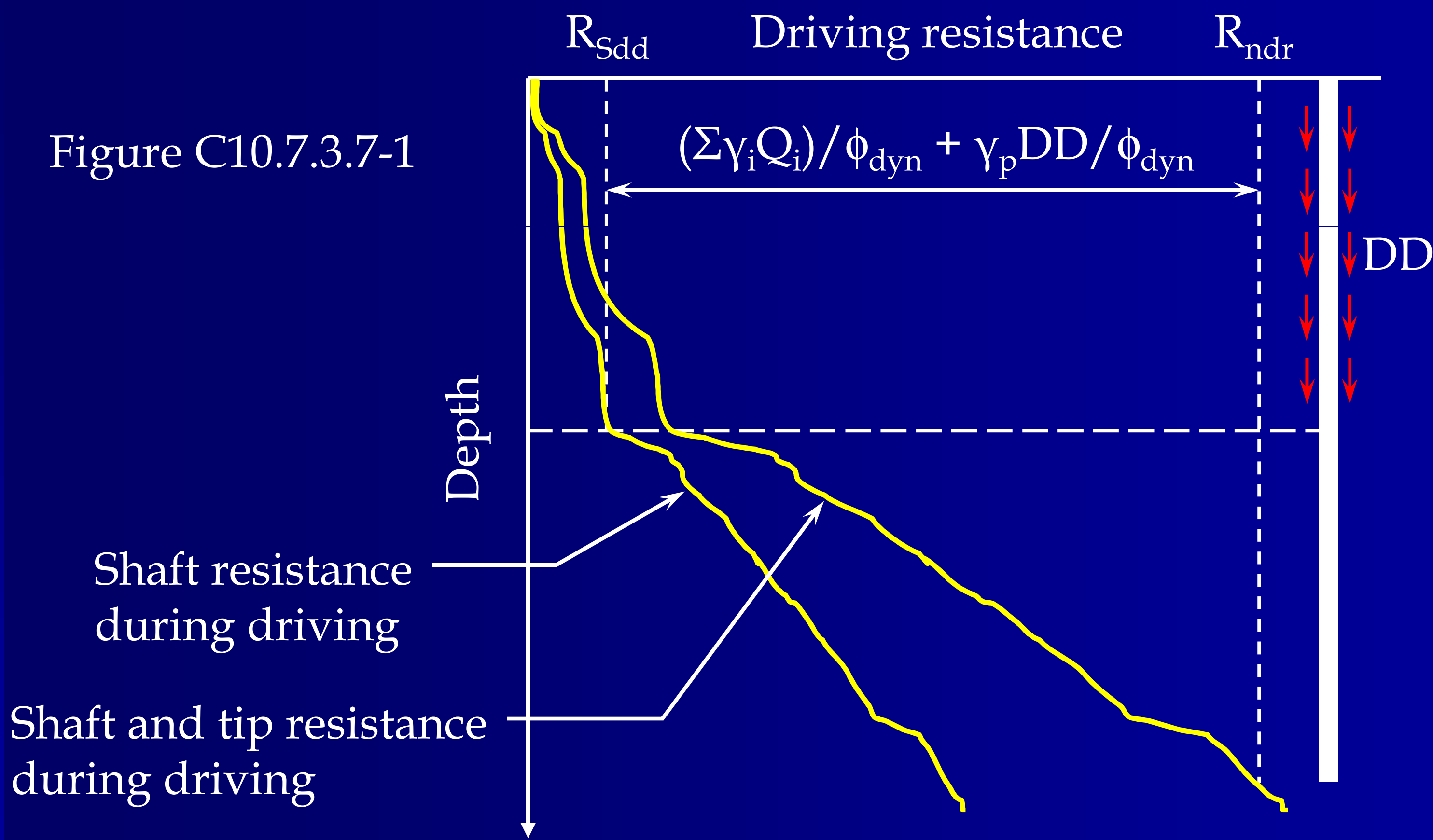
$$R_{ndr} \geq (\Sigma\gamma_i Q_i)/\phi_{dyn} + \gamma_p DD/\phi_{dyn} + R_{Sdd}$$

AASHTO LRFD Eq. C10.7.3.7-1 & Eq. C10.7.3.7-2

LRFD - Piles not driven to refusal

$$R_{ndr} \geq (\Sigma\gamma_i Q_i)/\phi_{dyn} + \gamma_p DD/\phi_{dyn} + R_{Sdd}$$

Figure C10.7.3.7-1



AASHTO LRFD
Piles not driven to refusal

Traditional Method

$R_{ndr} \geq (\Sigma\gamma_i Q_i)/\phi_{dyn} + \gamma_p DD/\phi_{dyn} + R_{Sdd}$

with permanent & transient loads

Neutral Plane Analysis

R_{ndr} ≥ the greater of the following:

$(\Sigma\gamma_i Q_i)/\phi_{dyn} + \gamma_p DD/\phi_{dyn} + R_{Sdd}$

with permanent loads only

or

$(\Sigma\gamma_i Q_i)/\phi_{dyn}$

with permanent & transient loads (no downdrag)

Methods for dealing with downdrag

- Use a larger H-pile section to increase factored structural resistance for piles on rock.
- Use more piles and reduce the applied load for piles not driven to refusal on rock.
- Reduce soil settlement that occurs after pile driving by preloading and/or using wick drains.
- Reduce soil settlement by using lightweight embankment fill material.
- Use bituminous pile coating.

Cautions regarding bituminous coating

It is often reported that bituminous coating is an effective and economical alternative for reducing downdrag. However, this has not been ODOT’s experience. It is generally more cost effective to increase the pile size.

2006 bid prices	Cost per LF
HP 10x42	$ 32
HP 12x53	$ 39
HP 14x73	$ 43
Bituminous Pile Coating	$ 25

Cautions regarding bituminous coating

- Bituminous coating reduces negative shaft resistance, but it also reduces positive shaft resistance.
- To determine the length of pile with coating, neutral plane analysis is required. Traditional method cannot be used.
- For bituminous coating to end up in the correct location, estimated pile lengths and settlement calculations must be accurate and not overly conservative.
- Bituminous coating can crack and spall off the pile during handling and driving.
- "Bitumen coating should not be casually specified as the solution to downdrag loading." Quote from *Design & Construction of Driven Pile Foundations*, FHWA

References

AASHTO LRFD Bridge Design Specifications, (2004) 3rd edition, with 2006 interim revisions

Design & Construction of Driven Pile Foundations (1996), FHWA-HI-97-013 www.fhwa.dot.gov/bridge/geo.htm (2006 version not available for free)

Briaud, J., & Tucker, L. (1997) "Design and Construction Guidelines for Downdrag on Uncoated and Bitumen-Coated Piles." *NCHRP Report 393,* Transportation Research Board

Fellenius, B.H. (2004) *Unified Design of Piled Foundations with Emphasis on Settlement Analysis,* www.fellenius.net