C6.2 Piles

C6.2.1 General

C6.2.1.1 Policy overview

Methods Memo No. 79: Integral Abutment Piles
24 July 2003

See C6.5.1.1.1.

C6.2.1.2 Design information

C6.2.1.3 Definitions

C6.2.1.4 Abbreviations and notation

C6.2.1.5 References

C6.2.2 Load application

C6.2.2.1 General

C6.2.2.2 Impact

C6.2.2.3 Downdrag

Methods Memo No. 140: New Plan Note E175/M175, "Waiting Period for Driving Piles"
2 November 2005

See C11.3.2.

Methods Memo No. 87: Revised Downdrag Calculations (Supersedes Methods Memo No. 20)
21 May 2004

Questions have been brought up recently about the office's policy on downdrag design. In some projects done recently, there were large downdrag forces found in the calculations making it difficult to do the pile design. After discussion, it was determined that the factor of safety for downdrag should be modified from 2 to 1.

Therefore, the downdrag will be entered in the notes as half the value currently used (the same value as the driving resistance in and above the compressible layer). The driving graph prepared by the Office of Design has a factor of safety of 2, therefore piles have an ultimate resistance of 2 times the plan total driving resistance. The factored downdrag force (2 * Chart Values) is resisted by the ultimate resistance of the material below the compressible layer (2 * chart values). Any variability in the downdrag load will be resisted by similar variability in the material below the compressible layer to pick up the load. Essentially a factor of safety of one is considered adequate for this application

The downdrag force should now be calculated as follows: (Note: Any soil in or above the compressible soil layers must be considered except for the prebore.)

1. Take the chart value for friction resistance from foundations soils information chart without any modification.
2. Down Drag Force = (Thickness of Soil Layer Above the Compressible Layer and below any prebore + Thickness of Compressible Soil Layer) * Chart Values for each soil layer.

Revised Example Calculations of Downdrag Forces for an Integral Abutment (See Methods Memo No. 20, 9-26-01 for original example)

This example assumes 150 tons loading due to LL and DL from the bridge and the following soils conditions:

Depth to layer	Material
0-12'	Fill
12-16'	Stiff Silty Clay
16-26'	Soft-Stiff Silty Clay (Compressible Layer)
26-36'	Firm Glacial Clay
>36'	Very Firm Glacial Clay

Note: The downdrag forces are determined from the allowable friction bearing values given in the Office of Design "Foundation Soils Information Chart" with the factor of safety (2) that is used for regular pile length bearing calculations. (Note: The downdrag forces should be calculated from the soil layers in and above the compressible layers.)

1. Calculate downdrag force:

Prebore	(0)(8 ft.)	=	0.0 tons
Medium Sand (Fill):	(0.6 tons/ft) (4 ft.)	=	2.4 tons
Stiff Silty Clay:	(0.3 tons/ft.) (4 ft.)	=	1.2 tons
Soft-Stiff Silty Clay:	(0.2 tons/ft.) (10 ft)	=	2.0 tons
Total Downdrag Force:		=	5.6 tons (49.8 kN)

2. Calculate Pile Lengths and Capacity:

Normal Capacity, HP10x42, Friction Pile (6 ksi): = 37 tons (329.2kN)
Reduced Capacity due to Down Drag: 37 tons – 5.6 tons = 31.4 tons (279.3 kN)

This capacity of 37 tons (329.2 kN) is calculated based on friction and end bearing below the compressible layer. The maximum load due to DL and LL from the bridge is limited to 31.4 tons (279.3 kN) because of the deduction for downdrag forces. However, the driving resistance may exceed the 37 tons (329.2 kN) bearing value as shown in the final calculated pile length table (41.2 tons or 366.5 kN).

Number of piles needed = 150/31.4 = 4.8 use 5
Load per pile = 150/5 = 30 tons (266.9 kN)
Calculate Pile Length:

Layer	Length (ft.)	Bearing Calc. (tons)	Σ Brg (tons)	Driving Resistance Calc (tons)	Σ. Driving Resist. (tons)
Embedment in Abut	2.0	NA	NA	NA	NA
Prebore	8.0	NA	NA	NA	NA
Fill	4.0	-(0.6 t/ft.)(4 ft.) =-2.4	-2.4	(0.6 t/ft)(4ft) = 2.4	2.4
Stiff Silty Clay	4.0	-(0.3 t/ft)(4 ft) = -1.2	-3.6	(0.3)(4 ft) = 1.2	3.6
Soft-Stiff Silty Clay (Compressible Layer)	10.0	-(0.2 t/ft)(10ft) = -2.0	-5.6	(0.2 t/ft)(10 ft) = 2.0	5.6
Firm Glacial Clay	10.0	(0.7 t/ft) (10 ft) = 7.0	1.4	(0.7 t./ft.)(10ft.) = 7.0	12.6
Very Firm Glacial Clay (< 30 ft Exist. Ground)	6.0	(0.7 t/ft)(6 ft) = 4.2	5.6	(0.7 t/ft)(6 ft) = 4.2	16.8
Very Firm Glacial Clay (> 30 ft Exist. Ground)	18.2	(1.0 t/ft)(18.2 ft) = 18.2	23.8	(1.0 t/ft)(18.2ft) = 18.2	35.0
End Bearing in Very Firm Glacial Clay	NA	(1000 psi)(12.4 in^2) / 2000 lb/t = 6.2	30.0	6.2	41.2

Note: Total length = 62.2 ft. therefore use 65 ft.

3. Provide the following note on the plan with the information filled in as shown:

"Abutment piles are designed to accommodate downdrag force due to soil consolidation under the new earth fill. Piles shall be driven to 41.2 tons based on theoretical driving resistance. This includes 5.6 tons of resistance in and above the compressible layers, 5.6 tons resistance for downdrag forces and 30.0 tons resistance for dead and live load bearing capacity."

Summary of example calculations:

1. Pile length is controlled by maximum allowable bearing value of 37 tons (HP10x42, 6 ksi allowable stress).
2. The driving resistance may exceed this value to a maximum of 12 ksi or 74.4 tons for the HP 10 x 42 pile that was used in the example.
3. The reduced DL + LL capacity of the pile is 31.4 tons. This value is used in determining the number of piles needed to carry the bridge loads at the abutment.
4. Theoretical pile length is based on actual number of piles divided into the total dead load and live load (150 tons / 5 piles equals 30 tons).
5. Plan pile length is rounded to the next 5-foot interval for steel piles (65 ft.).

Methods Memo No. 20: Downdrag Calculations for Piling (Superseded by Methods Memo No. 87) 26 September 2001

When including downdrag in the calculations for piling length and bearing the following guidelines shall be used.

1. The Soils Section of the Office of Design will indicate if there are any compressible soil layers on the foundation report.

2. Determine the design load of the piles due to the bridge Live Load and Dead Load.

3. Determine downdrag force as follows (Note: Any soil in or above the compressible soil layers must be considered except for the prebore.).
   a. Take chart value for friction resistance from foundations soils information chart and multiply by 2 to eliminate safety factor on values as shown in b.
   b. Down Drag Force = (Thickness of Soil Layer Above the Compressible Layer and below any prebore + Thickness of Compressible Soil Layer) * Chart Values for each soil layer * 2.

4. Determine Pile Length.
   a. Add design load and drag force to determine required pile capacity.
   b. Based on the required pile capacity determine the length of the pile needed below the compressible layer based on chart values for skin friction and end bearing.
   c. Total Pile Length = embedment of pile into footing and cutoff [1 ft. (305 mm)] + the pile length from bottom of footing to the bottom of the compressible layer + the pile length below compressible layer. Round pile length to even 1 ft (300 mm) for concrete piles and 5 ft (1500 mm) for wood or steel piles.

5. When calculating the bearing value for friction piles, include the downdrag forces when checking against the maximum allowable bearing capacity. For example for a HP10x42 steel friction pile, the total bearing capacity including downdrag forces should be 37 tons or less (6000psi * 12.4 in^2) / 2000 lbs/ton.

6. Determine Total Driving Resistance.

   Total Theoretical Driving Resistance = the driving resistance of all layers including any compressible layer for the plan pile length + the end bearing. (Note: Values for driving resistance shall be calculated directly from the values in the Soils charts, which include the factor of safety. Do not include the driving resistance in the prebore length.)

7. Add the following note to the plan.

“Abutment (or pier) piles are designed to accommodate downdrag force due to soil consolidation under the new earth fill. Piles shall be driven to ___ Tons (kN) based on theoretical driving resistance. This includes ___ Tons (kN) of resistance in and above the compressible layers, ___ Tons (kN) resistance for downdrag forces and ___ Tons (kN) resistance for dead and live load bearing capacity.”

Note: The maximum theoretical driving resistance should not be greater than 12 ksi (83 MPa) or 74.4 tons (660 kN) for HP10 x 42. Exceeding the maximum driving resistance may be a problem. For situations where you exceed the 9 ksi (62 MPa) driving resistance, a request for a wave equation analysis of the piles should be made through the Construction Office. The Office of Construction will evaluate the wave equation stresses to determine if there are any overstresses. If overstresses are a problem then check with your section leader for options to eliminate the overstresses. Options available may be to increase the number of piles and reduce the lengths or provide a higher strength pile (50 ksi, 345 MPa).

Example Calculations of Downdrag Forces for an Integral Abutment

This example assumes 150 tons loading due to LL and DL from the bridge and the following soils conditions:

Depth to layer	Material
0-12'	Fill
12-16'	Stiff Silty Clay
16-26'	Soft-Stiff Silty Clay (Compressible Layer)

26-36'	Firm Glacial Clay
>36'	Very Firm Glacial Clay

Note: The downdrag forces are determined from the allowable friction bearing values given in the Office of Design "Foundation Soils Information Chart" without the factor of safety (2) that is used for regular pile length bearing calculations. In order to remove the factor of safety, multiply the chart values by 2.0 when calculating downdrag forces. (Note: The downdrag forces should be calculated from the soil layers in and above the compressible layers.)

1. Calculate downdrag force:

Prebore	0	(8 ft.)	=	0.0 tons
Medium Sand (Fill):	2 (0.6 tons/ft) (4 ft.)		=	4.8 tons
Stiff Silty Clay:	2 (0.3 tons/ft.) (4 ft.)		=	2.4 tons
Soft-Stiff Silty Clay:	2 (0.2 tons/ft.) (10 ft)		=	4.0 tons
Total Downdrag Force:		=		11.2 tons (99.6 kN)

2. Calculate Pile Lengths and Capacity:

Normal Capacity, HP10x42, Friction Pile (6 ksi):	=	37 tons (329.2kN)
Reduced Capacity due to Down Drag: 37 tons – 11.2 tons	=	25.8 tons (229.6 kN)

This capacity of 37 tons (329.2 kN) is calculated based on friction and end bearing below the compressible layer. The maximum load due to DL and LL from the bridge is limited to 25.8 tons (229.6 kN) because of the deduction for downdrag forces. However, the driving resistance may exceed the 37 tons (329.2 kN) bearing value as shown in the final calculated pile length table (41.8 tons or 371.9 kN).

Number of piles needed = 150/25.8 = 5.8 use 6
Load per pile = 150/6 = 25 tons (222.4 kN)
Calculate Pile Length:

Layer	Length (ft.)	Bearing Calc. (tons)	Σ Brg (tons)	Driving Resistance Calc (tons)	Σ. Driving Resist. (tons)
Embedment in Abut	2.0	NA	NA	NA	NA
Prebore	8.0	NA	NA	NA	NA
Fill	4.0	-2.0 (0.6 t/ft.)(4 ft.) = -4.8	-4.8	(0.6 t/ft)(4ft) = 2.4	2.4
Stiff Silty Clay	4.0	-2.0 (0.3 t/ft)(4 ft) = -2.4	-7.2	(0.3)(4 ft) = 1.2	3.6
Soft-Stiff Silty Clay (Compressible Layer)	10.0	-2.0 (0.2 t/ft)(10ft) = -4.0	-11.2	(0.2 t/ft)(10 ft) = 2.0	5.6
Firm Glacial Clay	10.0	(0.7 t/ft) (10 ft) = 7.0	-4.2	(0.7 t./ft.)(10ft.) = 7.0	12.6
Very Firm Glacial Clay (< 30 ft Exist. Ground)	6.0	(0.7 t/ft)(6 ft) = 4.2	0	(0.7 t/ft)(6 ft) = 4.2	16.8
Very Firm Glacial Clay (> 30 ft Exist. Ground)	18.8	(1.0 t/ft)(18.8 ft) = 18.8	18.8	(1.0 t/ft)(18.8ft) = 18.8	35.6
End Bearing in Very Firm Glacial Clay	NA	(1000 psi)(12.4 in^2) / 2000 lb/t = 6.2	25.0	6.2	41.8

Note: Total length = 62.8 ft. therefore use 65 ft.

3. Provide the following note on the plan with the information filled in as shown:

"Abutment piles are designed to accommodate downdrag force due to soil consolidation under the new earth fill. Piles shall be driven to 41.8 Tons based on theoretical driving resistance. This includes 5.6 Tons   of resistance in and above the compressible layers, 11.2 Tons resistance for downdrag forces and 25.0 Tons   resistance for dead and live load bearing capacity."

Summary of example calculations:

6. Pile length is controlled by maximum allowable bearing value of 37 tons (HP10x42, 6 ksi allowable stress).
7. The driving resistance may exceed this value to a maximum of 12 ksi or 74.4 tons for the HP 10 x 42 pile that was used in the example.
8. The reduced DL + LL capacity of the pile is 25.8 tons. This value is used in determining the number of piles needed to carry the bridge loads at the abutment.

C6.2.3 Service load groups and application to piles

C6.2.4 Analysis and design

Methods Memo No. 55: Use of Higher Pile Capacities
5 November 2001

See C6.2.6.1.

Methods Memo No. 9: Battered Pile Capacity and Lateral Load Capacity for Pier Design
9 April 2001

Questions have been raised about whether the capacity of battered piles should be reduced because of the 4:1 batter typically used in pier footings. Based on discussions that I have had with the section leaders, it was decided not to reduce pile capacity for battered piles. The same capacity should be used for the battered piles that are used for the vertical piles.

Another related question that was recently brought up was whether a check of the shear capacity of the piles should be made based on the lateral loads that are applied to the pier. In the past the lateral capacity of the piles has not been a problem for pier design, but the capacity should still be checked. With the longer spans and larger lateral wind and temperature forces that are being applied to the piers, the pile design may be controlled by the lateral loads. If lateral loads are controlling your pile design, inform your section leader. When checking the lateral capacity, use the same allowable lateral capacity for piles that we use in the stub abutment design of 4 kips/pile for wood piles and 6 kips/pile for steel piles.

Methods Memo No. 14: Prebore Lengths for Integral and Stub Abutments
13 September 2001 (Note that standard prebore length now is 10 feet (3.050 m). See Methods Memo No. 23 in C6.5.1.1.1.)

When determining pile lengths for integral and stub abutments, downdrag forces may need to be included in the design. To help reduce the effects of the downdrag forces, the designer may consider increasing the prebore depths (standard length 8 ft. (2400 mm)) for the integral abutment piling or providing prebore for stub abutments piling.

If the prebore length is increased, the maximum prebore lengths should be as follows.

1. For integral abutments, a maximum prebore length of 15 ft (4500 mm).
2. For stub abutments, a maximum prebore length of 20 ft (6000 mm).

These lengths are based on the office’s experience with longer prebores and stability checks of the piling using the following assumptions:

1. A maximum deflection of 1 ½ inch (40 mm) or 3 inches (75 mm) total movement for the integral abutments. Note: This deflection includes setting factors of 1.5 for prestressed beams and 1.33 for steel girders.
2. No lateral deflection of the stub abutment.
3. Using HP10 x 42 (250 x 62) steel piles with a maximum bearing of 55 tons (489 kN)
4. No lateral support from the bentonite slurry that is currently used as back fill in the prebore.
5. A minimum pile length of 2.5 times the prebore length. If this length cannot be reached than a special analysis needs to be done.

In situations, where the prebore needs to be increased or included in the abutment design, please check with you section leader for approval.

C6.2.5 Detailing

Methods Memo No. 117: Pile Cutoff for Battered Piles
20 July 2005

The Office of Construction recently brought up an issue concerning the details used to show the tops of battered piles in pier footings. On a recent bridge project, the cutoff of the tops of the battered piles were shown as normal to the centerline of the pile. Construction's preference is to show the pile top as a level (horizontal) surface. This allows easier placement of footing reinforcement when it is placed directly above the battered piling in pier footings. The top of the battered pile may interfere with placement of reinforcing unless it is trimmed horizontal.

Therefore, in bridge plans with pier footings where the footing reinforcement is located directly above the piles, the following note should be added to the pier general notes and the battered piles detailed to show a horizontal surface.

E724/M724 "All battered pile shall be trimmed to a horizontal line to aid in the placement of reinforcing".

Prestressed piles, which are normally driven to full penetration should not be trimmed, because of the difficulty and cost of removing the corner of the concrete to provide a horizontal surface.

C6.2.6 Guidelines by pile type

C6.2.6.1 Steel H

Because of relatively high driving stresses the Office of Construction initiated a change in the steel H-pile specification from ASTM A 36/A 36M to ASTM A 572/A 572M. The change will be effective in October 2005. This change in steel specification does not affect the maximum allowable stresses for structural design.

Methods Memo No. 55: Use of Higher Pile Capacities
5 November 2001

Existing Iowa DOT guidelines for the design of piles should be followed with the following exceptions: For steel piles that are designed for point bearing and seated in bedrock with N-values between 100-200, you may include contribution from side friction, if the soil layers penetrated consist of suitable material. The total design stress on the pile may exceed 6 ksi (42 MPa) but shall not exceed 9 ksi (62 MPa).

C6.2.6.2 Concrete-filled steel pipe

C6.2.6.3 Timber

Methods Memo No. 48: Pile Design High Skew Slab Bridges
In process

See C6.2.6.1.

C6.2.6.4 Prestressed concrete