

Remedial Foundation Solutions for Existing Tanks

2009 Aboveground Storage Tank
Management Conference and Trade
Show

September 11, 2009 – Houston, Texas

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BAKER**
Geotechnical Construction



Presentation

- ◆ **Types of Settlement**
- ◆ **Remedial Methods**
 - Grouting
 - Mechanical Jacking
 - Floor Lifting
- ◆ **Case History**
- ◆ **Close**

Settlement Types

◆ Shell Settlement

- $S \leq [(L^2 \times Y \times 11)/(2 \times E \times H)]$

◆ Edge Settlement

- Maximums set by API and depend on the tank construction

◆ Internal Bottom Settlement

- $B_B = 0.37R$
- Edge and center settlement relationship
 - $(r_{\text{center}} - r_{\text{edge}})/D < 0.005$

Settlement Types

- ◆ **Settlement of Tanks can lead to ...**
 - Overstressing of tank connections
 - Loss of Freeboard
 - Distortion of roofs
 - Ovalization of Fluid Surface
 - Overstressing of shell
 - Overstressing of floor
- ◆ **Settlement is related to poor or non uniform ground conditions**

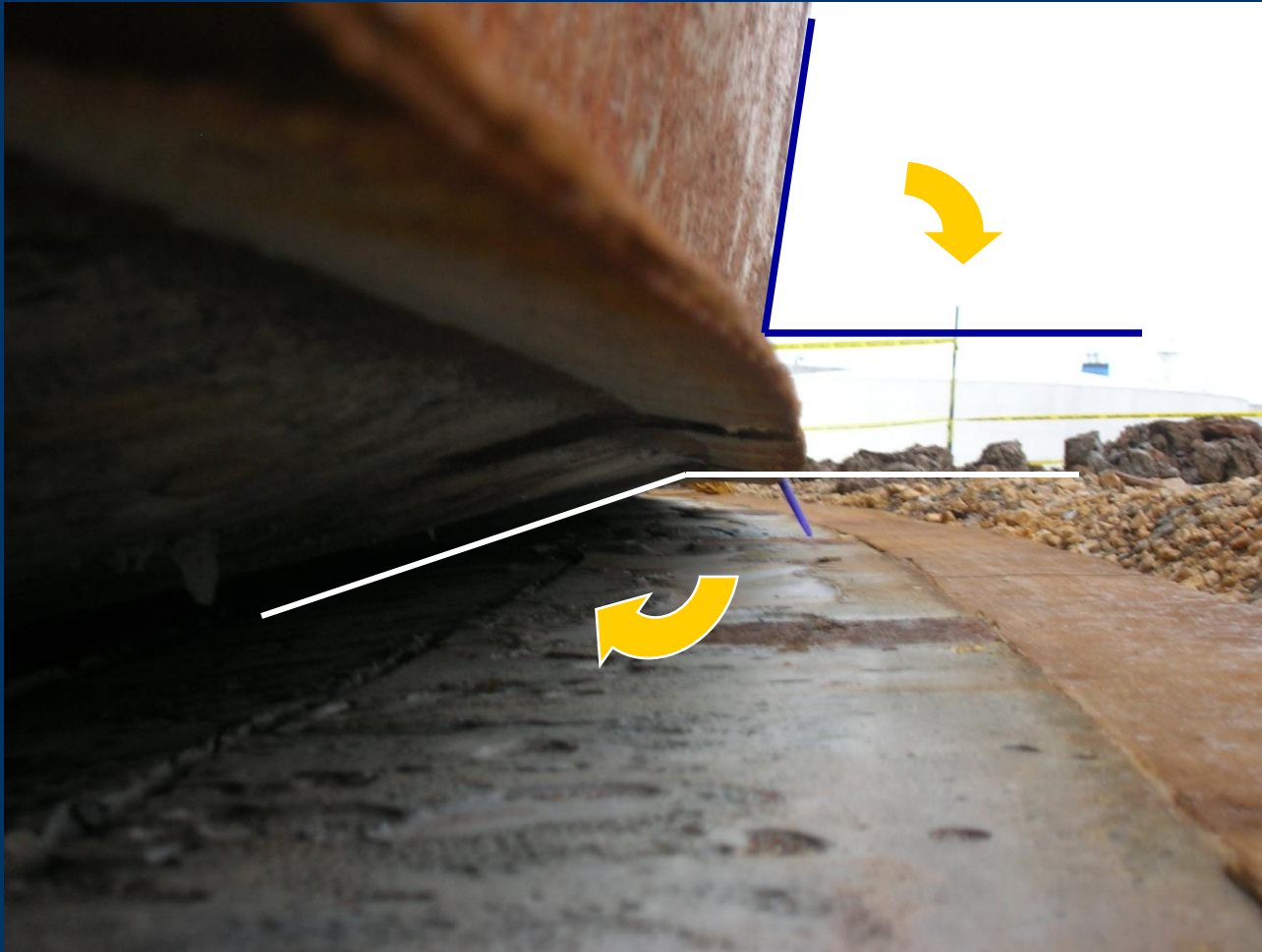
Shell Settlement



Internal Bottom Settlement



Edge Settlement



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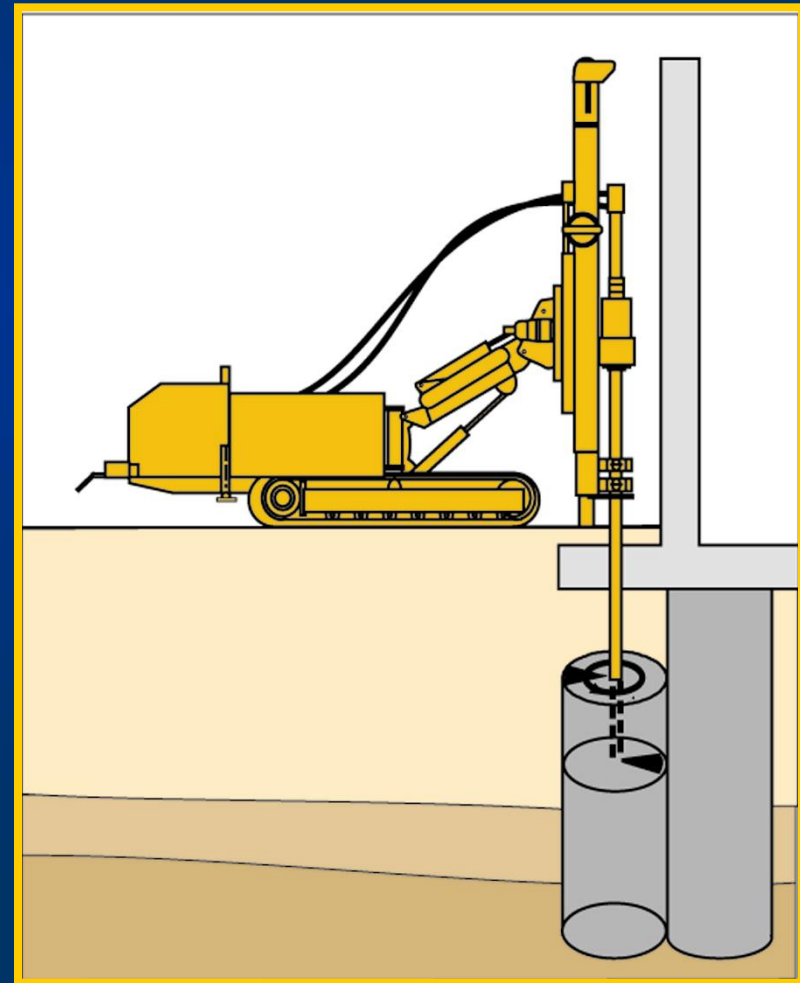
Remedial Methods

- ◆ **Jet Grouting**
 - Insitu buttress
 - Insitu ring beam
- ◆ **Compaction Grouting**
 - Densification of loose soil
 - Lift settled ring beams
- ◆ **Micropiles**
- ◆ **Slurry Grouting**
- ◆ **Mechanical Lifting**

Jet Grouting

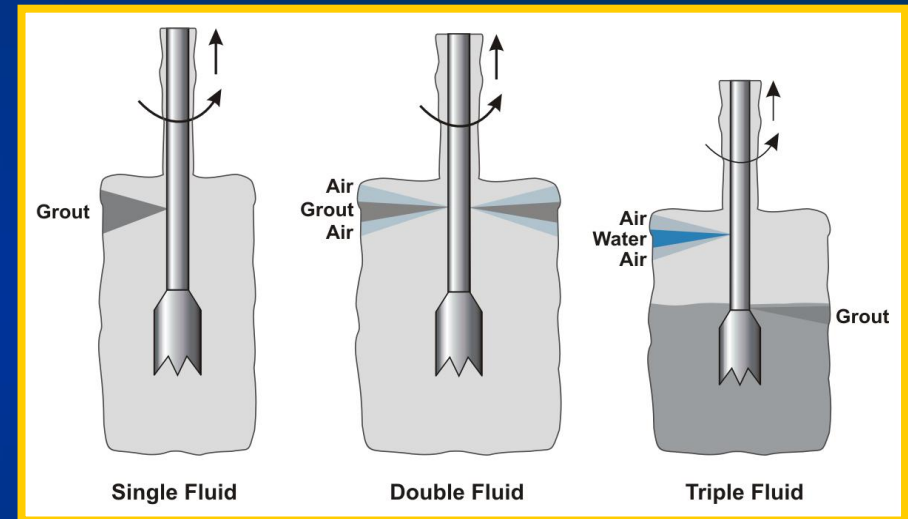
Jet Grouting is a versatile Ground Modification system used to create in situ cemented geometries of soilcrete.

SuperJet Grouting is a modified double-fluid jet grouting system that takes advantage of tooling design efficiencies and increased energy to create high-quality, large diameter (11-16 ft), soilcrete elements. It is effective in most soil types and is best when applied for bottom seals and 'surgical' treatment applications.

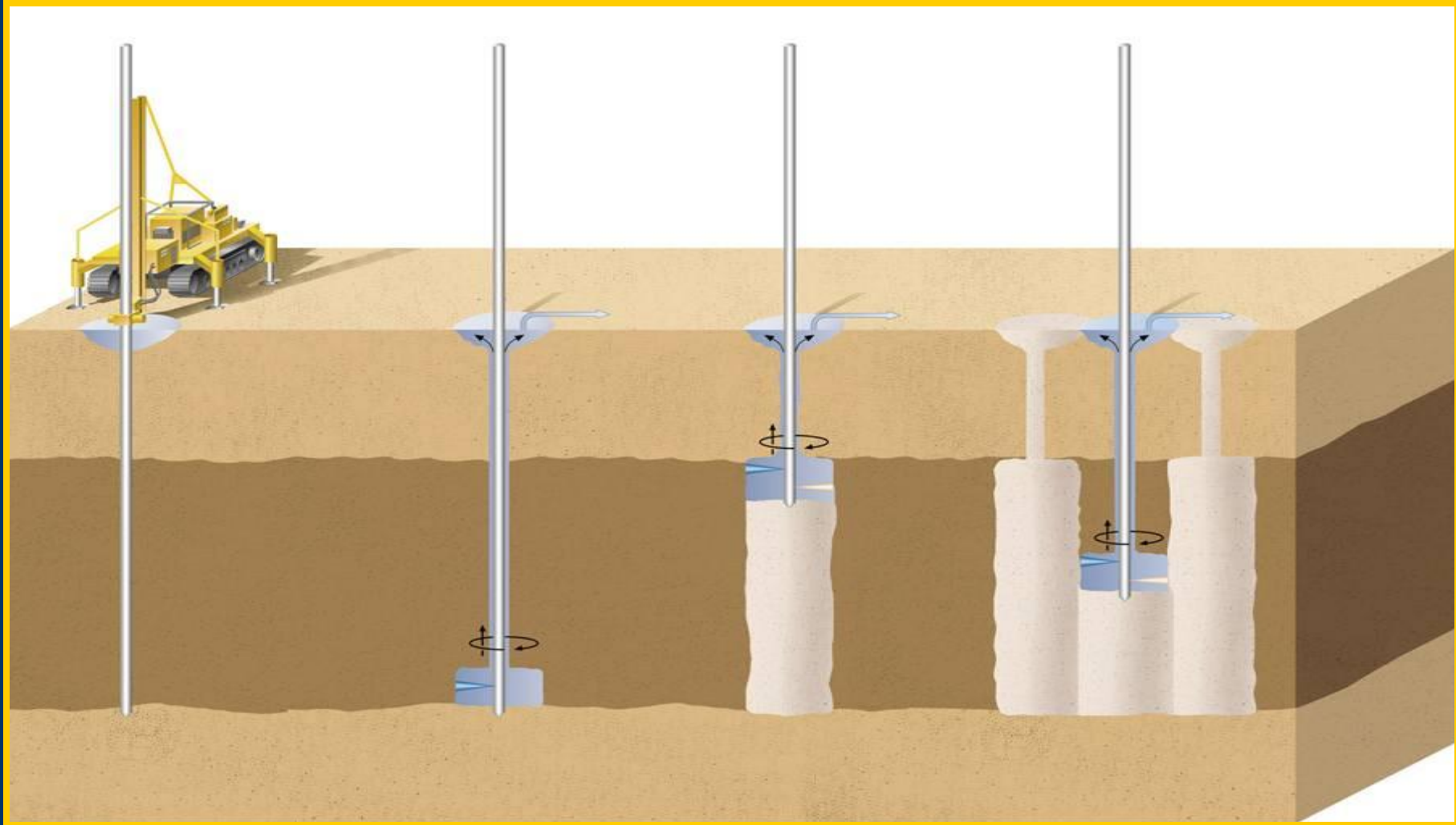


Jet Grouting Systems

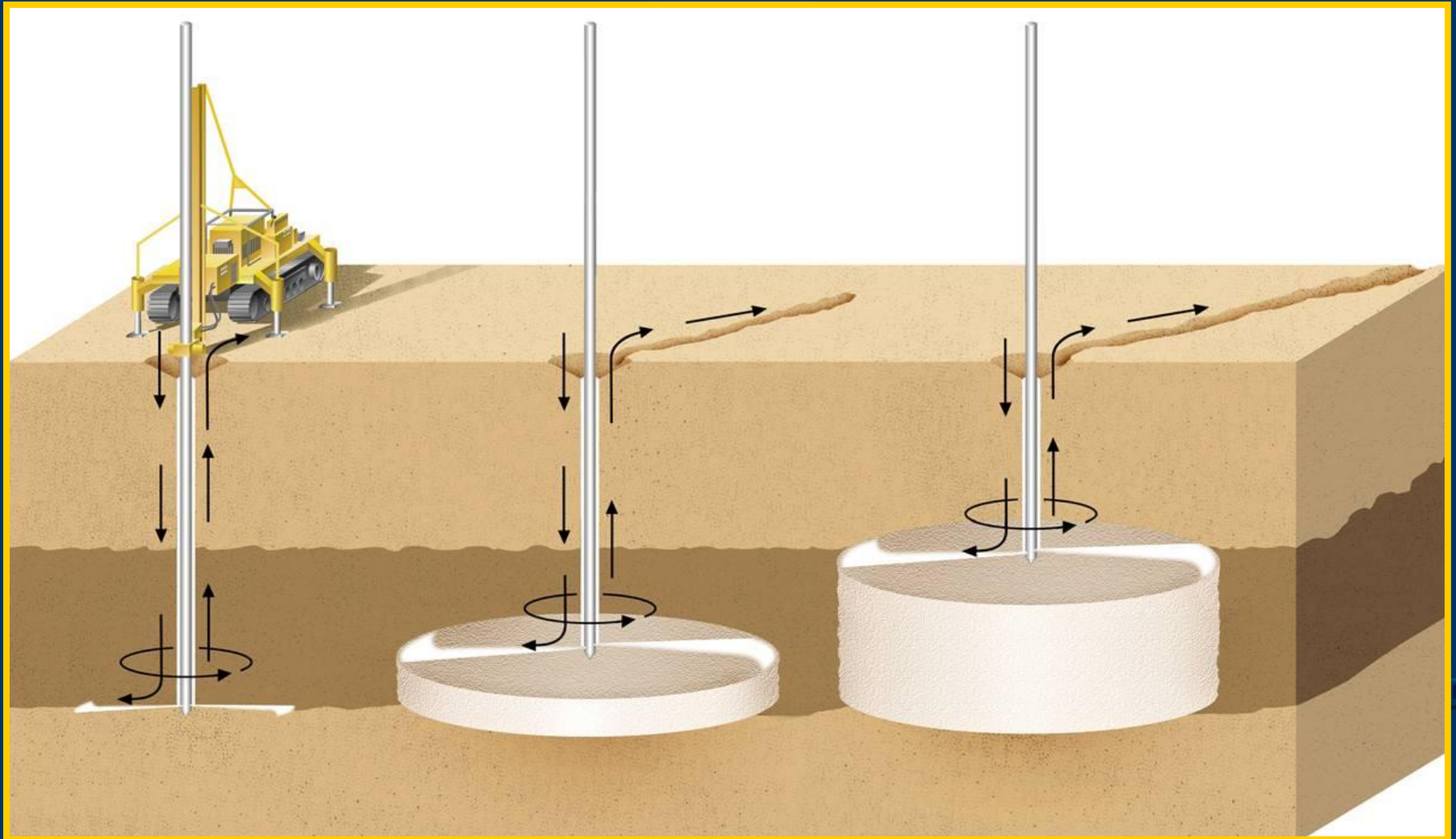
There are three traditional jet grouting systems. Selection of a system is generally determined by the in situ soil, the application, and the physical characteristics of soilcrete (i.e. strength) required for that application.



Jet Grouting Process



SuperJet Grouting Process

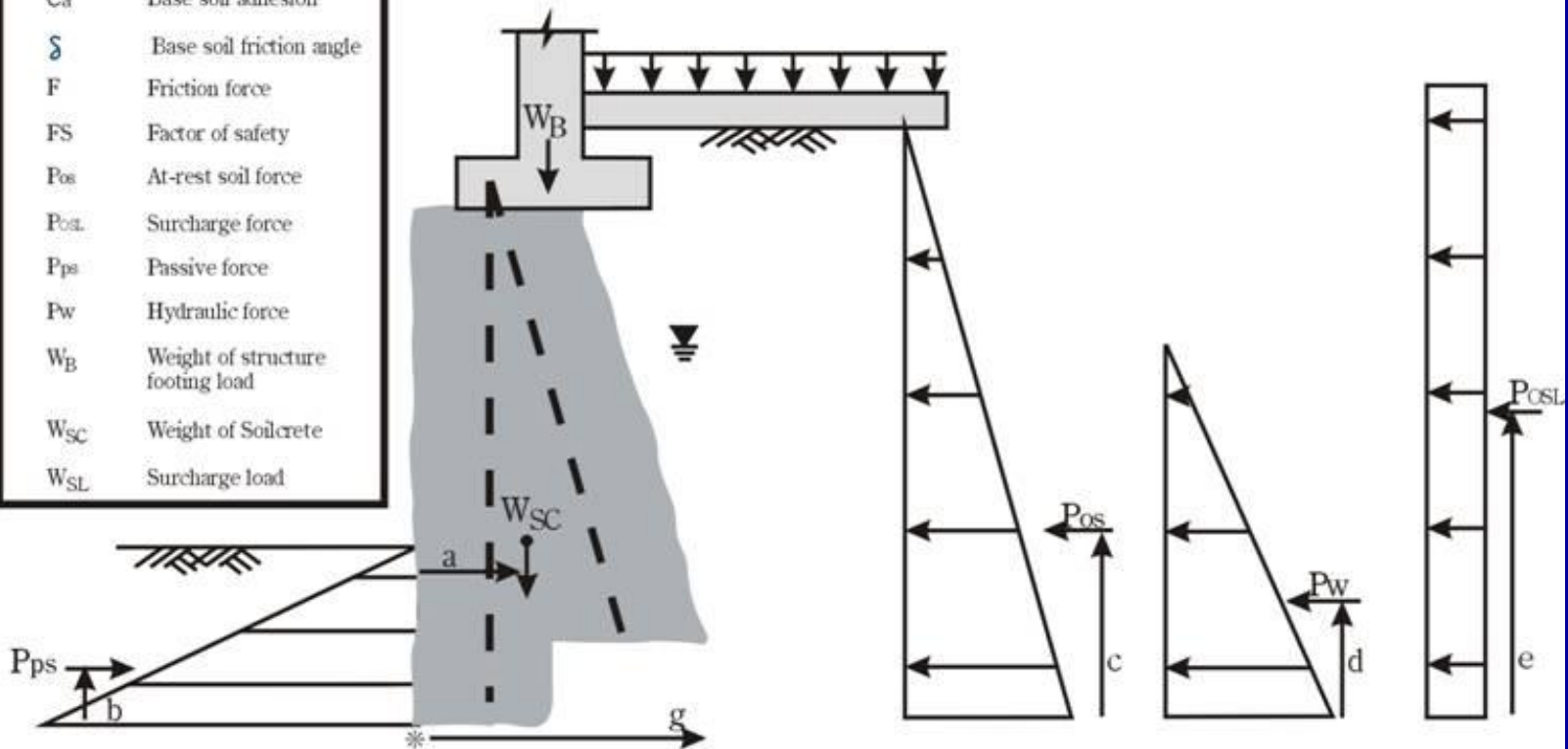




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Design Considerations for Jet Grout Buttress Construction

LEGEND	
a,b,c,d,e	Moment arms
Ca	Base soil adhesion
δ	Base soil friction angle
F	Friction force
FS	Factor of safety
Pos	At-rest soil force
Pos.	Surcharge force
Pps	Passive force
Pw	Hydraulic force
WB	Weight of structure footing load
W _{SC}	Weight of Soilcrete
W _{SL}	Surcharge load



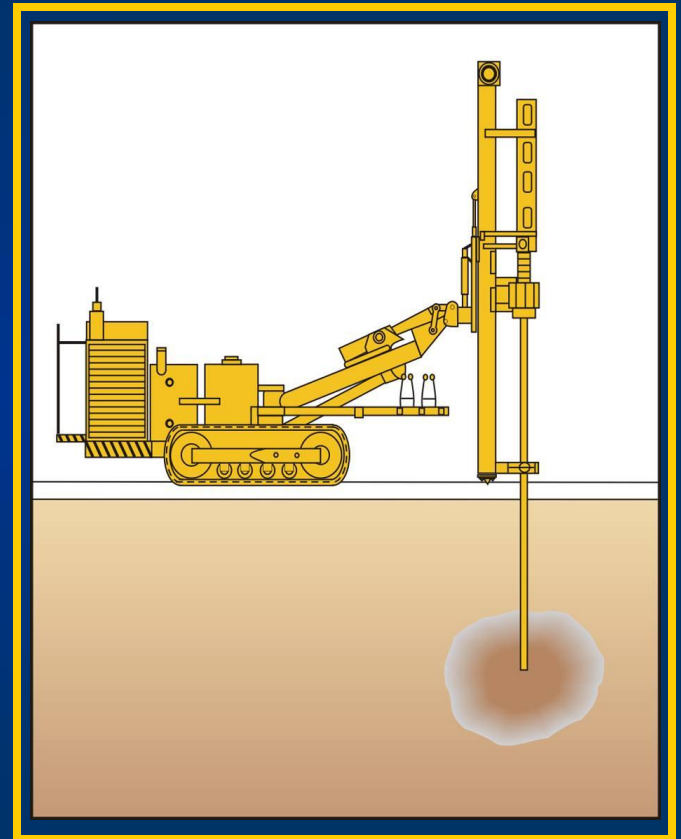
$$F = (W_B + W_{SC}) \tan \delta + g \cdot Ca$$

$$FS \text{ overturning}^* = \frac{(W_B + W_{SC}) a + P_{ps} \cdot b}{(P_{os} \cdot c) + (P_w \cdot d) + (P_{osL} \cdot e)} \geq 1.5 \quad FS \text{ sliding} = \frac{P_{ps} + F}{P_{os} + P_w + P_{osL}} \geq 1.5$$

Compaction Grouting

Compaction Grouting uses displacement to improve ground conditions. A very viscous (low-mobility), aggregate grout is pumped in stages, forming grout bulbs, which displace and densify the surrounding soils.

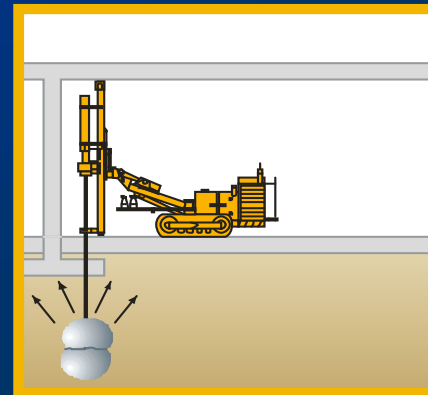
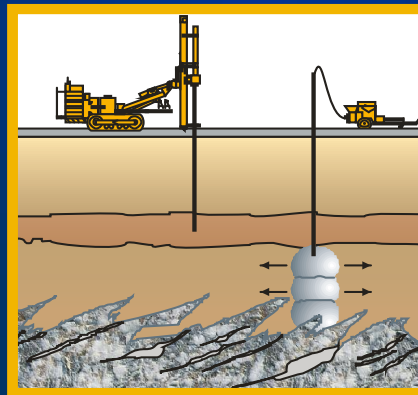
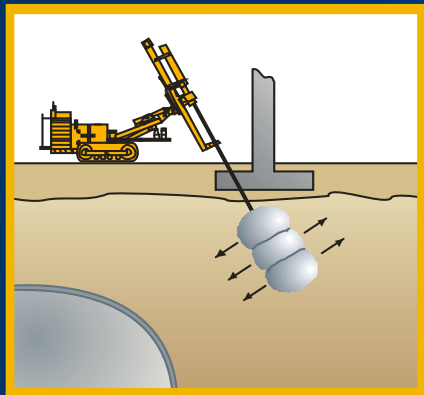
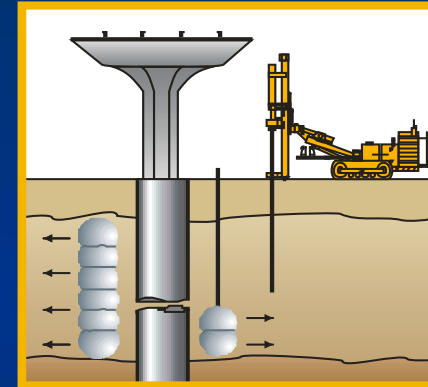
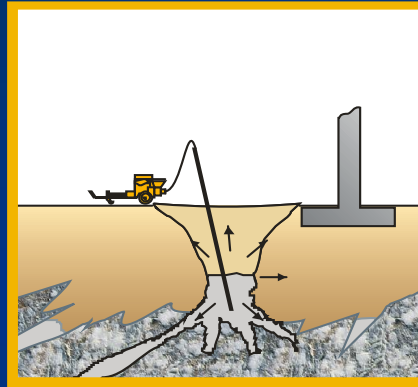
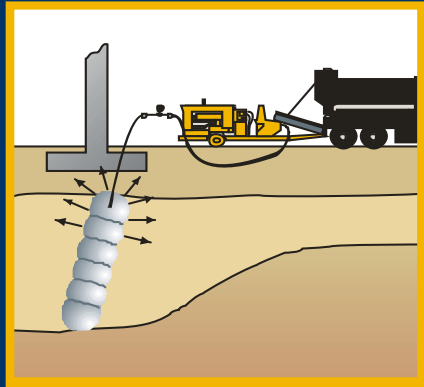
Significant improvement can be achieved by sequencing the grouting work from primary to secondary to tertiary locations.



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Compaction Grouting Applications





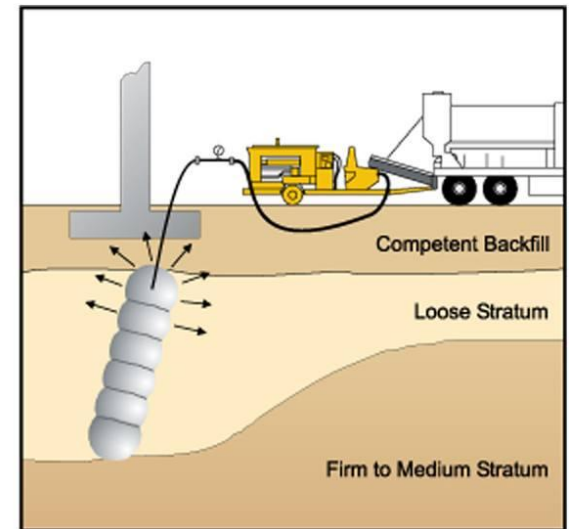
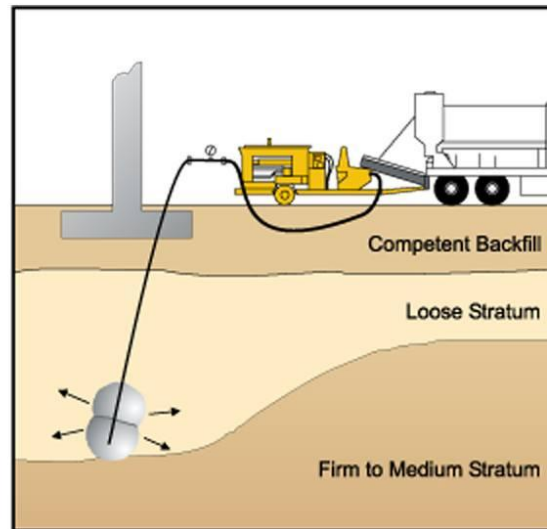
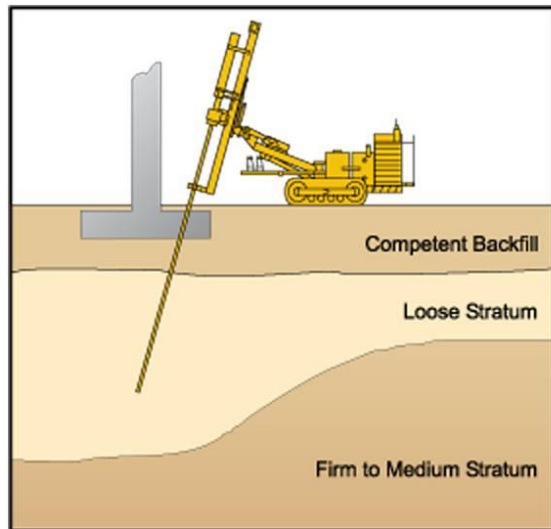
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Compaction Grouting Process

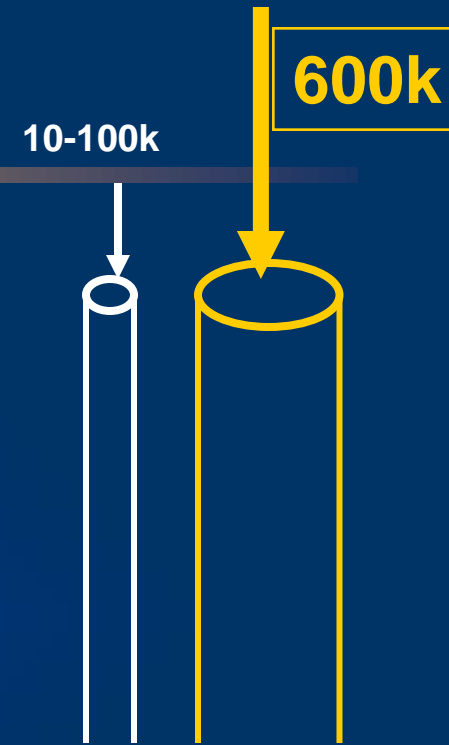


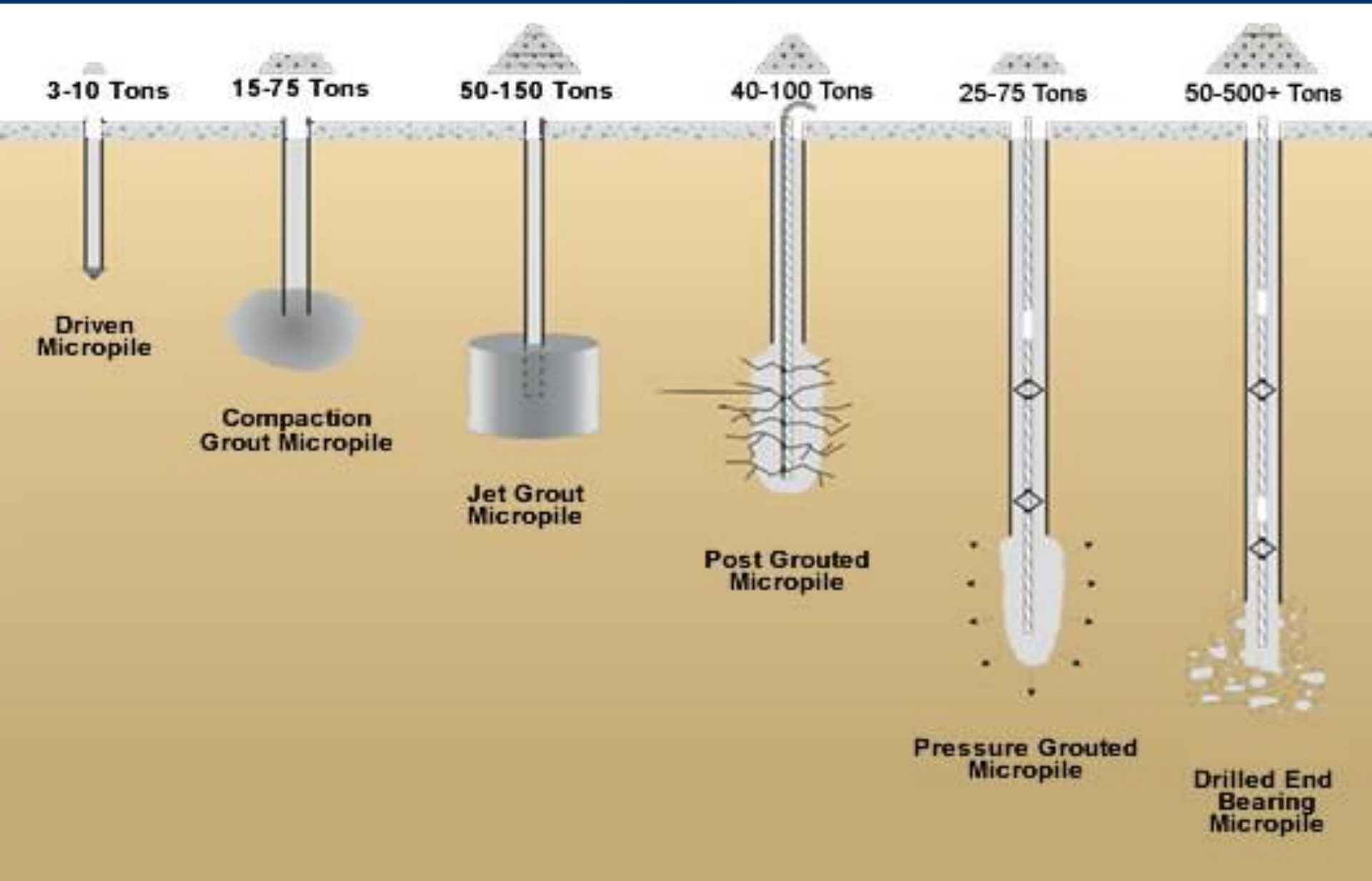




Micropiles

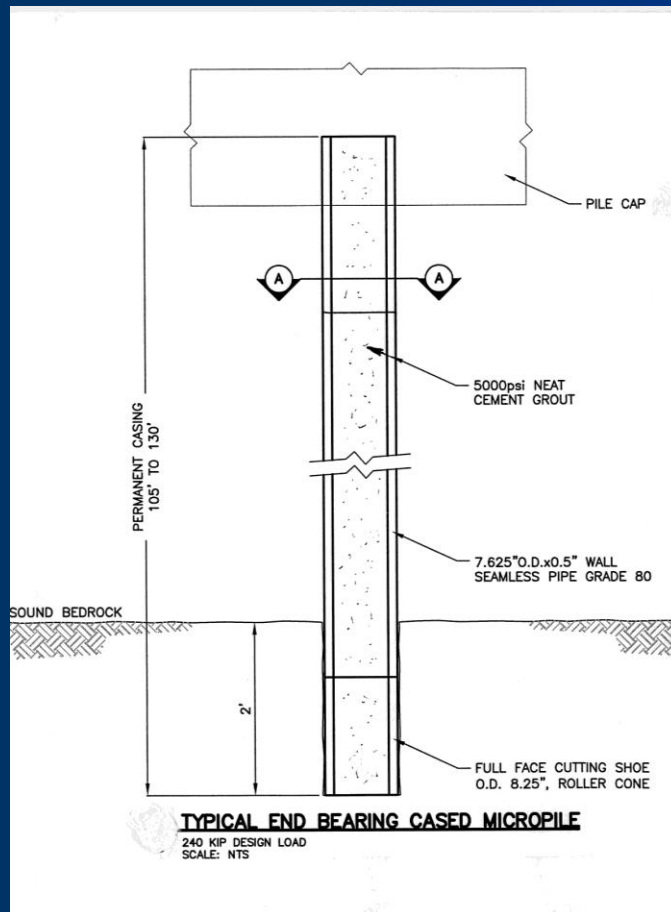
- ◆ Originally...were relatively small diameter (2 to 5"), low capacity piles (10 to 100 kips) used in various soil types to transfer structural load to competent bearing strata. Micropiles are easily installed in restricted access and limited headroom situations.
- ◆ Now...diameters and capacities have increased to as great as 12" and 600 kips, respectively.





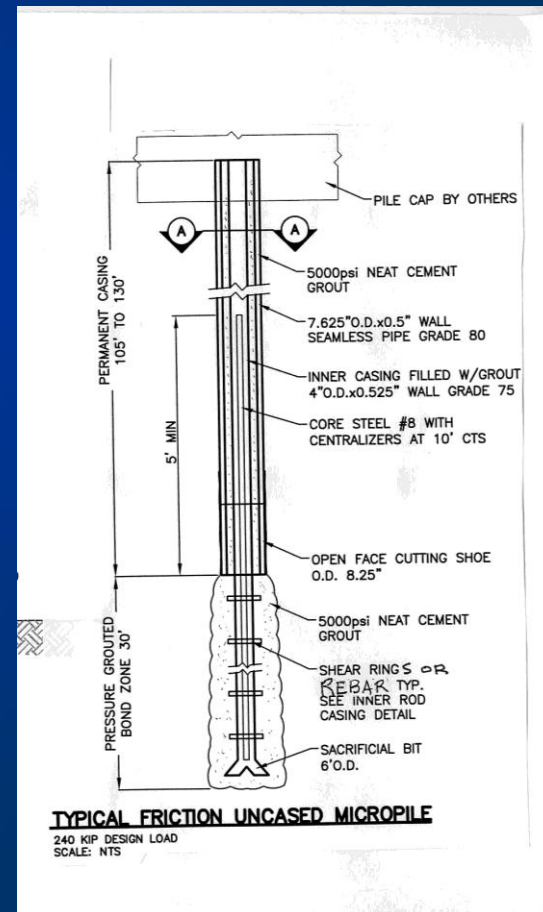
Two Types Of Micropiles

- ◆ **CASED - Steel Pipe
Cement Grout Core**



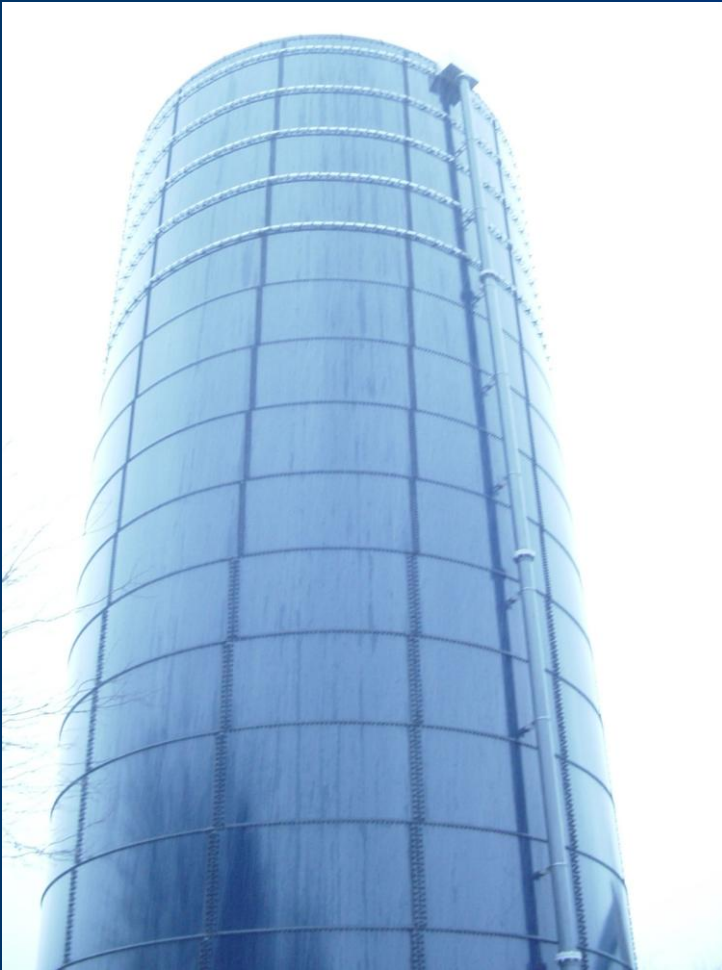
End Bearing Pile

- ◆ **UNCASED - Pressure Grouted
Shaft with Steel Core**



Friction Pile

Micropiles



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Micropiles for Tanks



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Mechanical Lifting/Grouting



Mechanical Lifting



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Case History

- ◆ Tank supported on ring beam
- ◆ Settlement exceeded tolerances during hydrotest
- ◆ Hydrotest stopped prior to full height reached
- ◆ Ring beam structure compromised

Jet Grouting - Tanks

◆ Design was based upon...

- Good Bearing soils at depth
- Settlement would be rectified using compaction grouting
- Treatment isolated to side of tank with most settlement
- Jet Grout columns installed through and below ring beam
- 3 to 4 ft diameter jet grout column

Jet Grouting Tanks

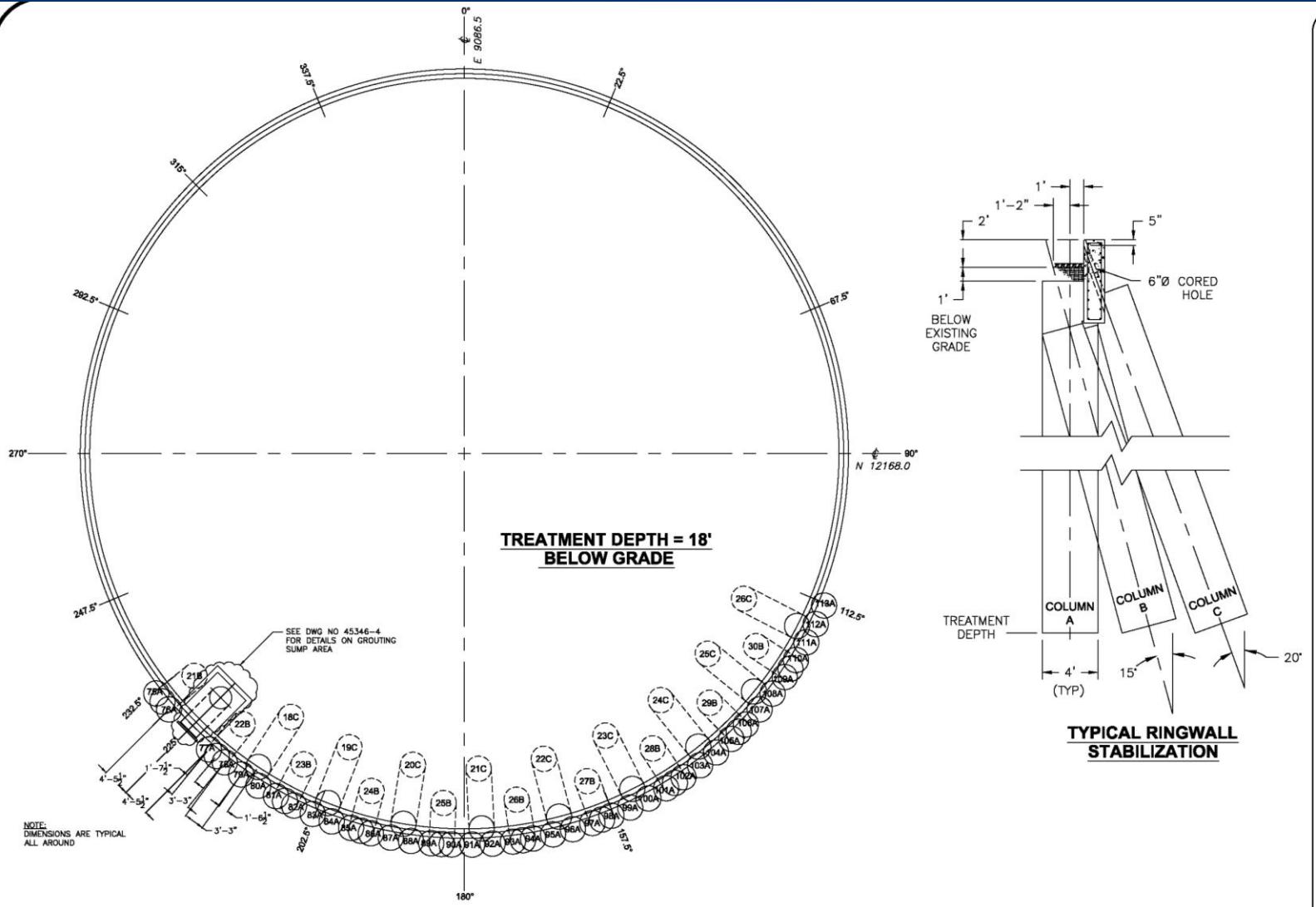
Tank 516
Ringwall foundation

Water	0.0 ft	22 ft	42 ft	53.5 ft	53.5 ft	53.5 ft	53.5 ft	53.5 ft					
Date	1/25/2008	3/26/2008	3/27/2008	3/29/2008	3/31/2008	4/2/2008	4/3/2008	4/4/2008					
Survey Pt.													
0	5.94	0	5.9	0	5.69	0	5.64	0	5.62	0	5.61	0	5.6
1	5.93	1	5.92	1	5.86	1	5.77	1	5.72	1	5.71	1	5.69
2	5.94	2	5.94	2	5.9	2	5.83	2	5.8	2	5.8	2	5.78
3	5.96	3	5.96	3	5.92	3	5.87	3	5.86	3	5.85	3	5.84
4	5.97	4	5.97	4	5.94	4	5.9	4	5.89	4	5.88	4	5.87
5	5.97	5	5.94	5	5.93	5	5.88	5	5.87	5	5.85	5	5.83
6	5.97	6	5.94	6	5.92	6	5.86	6	5.83	6	5.81	6	5.78
7	5.96	7	5.93	7	5.89	7	5.8	7	5.76	7	5.73	7	5.71
8	5.94	8	5.9	8	5.85	8	5.74	8	5.68	8	5.64	8	5.61
9	5.93	9	5.87	9	5.82	9	5.67	9	5.61	9	5.57	9	5.54
10	5.97	10	5.88	10	5.82	10	5.65	10	5.59	10	5.55	10	5.52
11	5.92	11	5.83	11	5.77	11	5.6	11	5.52	11	5.5	11	5.46
12	5.96	12	5.86	12	5.8	12	5.65	12	5.59	12	5.56	12	5.54

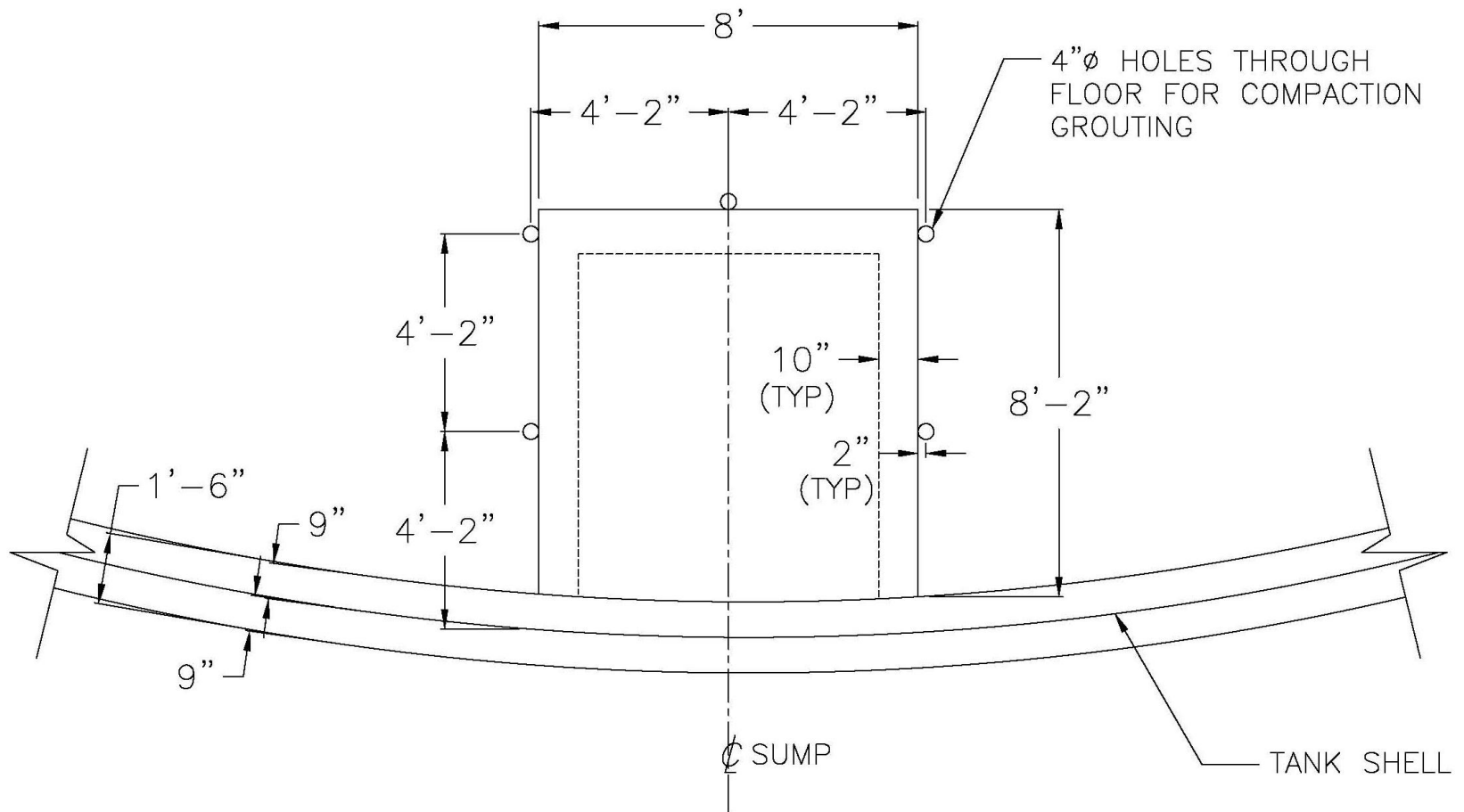
Water	53.5 ft
Date	4/5/2008
Survey Pt.	
0	5.6
1	5.69
2	5.79
3	5.84
4	5.87
5	5.85
6	5.8
7	5.72
8	5.62
9	5.55
10	5.52
11	5.47
12	5.54

Tank Settlement	
in Tenths	in Inches
0.34	4.08"
0.24	2.88"
0.15	1.80"
0.12	1.44"
0.1	1.20"
0.12	1.44"
0.17	2.04"
0.24	2.88"
0.32	3.84"
0.38	4.56"
0.45	5.40"
0.45	5.40"
0.42	5.04"

Jet Grouting Tanks



Jet Grouting Tanks



Jet Grouting Tanks



Jet Grouting Tanks



Closing Remarks

- ◆ Tanks can fail from differential settlement which overstresses the shell or floor
- ◆ Product capacity can be compromised due to settlements
- ◆ Connections to the tank can be compromised due to settlements
- ◆ Grouting methods can be employed to minimize additional settlement or rectify settlement that has already taken place

Closing Remarks

- ◆ **Compaction Grouting can be used to raise settled portions of a tank**
- ◆ **Jet Grouting can be used to increase edge shear**
- ◆ **Micropiles can be used to support heavily reinforced tank slabs and ring beams**

The World as we See It!



**Thanks for
listening!**

Questions?

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