O-CELL TESTING CASE HISTORIES DEMONSTRATE THE IMPORTANCE OF BORED PILE (DRILLED SHAFT) CONSTRUCTION TECHNIQUE

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ABSTRACT

Herein we review the Osterberg Cell, or O-cell, method for performing large capacity load tests on bored piles (drilled shafts), and demonstrate how it provides a new opportunity to assess the effects of construction technique. A sampling of 8 case histories, 7 with comparative testing, illustrates the impact of poor technique and thus demonstrates the importance of good construction technique. The poor techniques include inadequate bottom cleanout, failure to use drilling fluids, poor concrete placement, failure to roughen sides, and improper drilling tools. We conclude with a brief description of a recent, world record, 133 MN (15,000 tons) O-cell load test.

KEYWORDS

Bored piles, drilled shafts, Osterberg cell testing, construction methods, case histories, load testing, world record, large capacity

REVIEW OF O-CELL TESTING METHOD

The development and use of the Osterberg Cell, or O-cell, method for the high capacity, static testing of bored piles gives engineers a new and powerful tool to evaluate the effects of pile construction techniques. The following briefly reviews the method and then presents 8 case histories illustrating the effects of various poor construction techniques. A final, 9th case history, presents a new world record example of the achievable capacity using good construction techniques.

Simply put, the O-cell is a sacrificial jack-like device which the Engineer can have installed at the tip of a driven pile or at any elevation on the reinforcement cage of a bored pile. It provides the static loading and requires no overhead frame or other external reaction system. Figure 1 illustrates schematically the difference between a conventional load test and an O-cell test. A conventional test utilizes an overhead reaction system or dead load to load the bored pile in compression at its top. Side shear F and end bearing Q combine to resist the top load P. The engineer can separate these components approximately only by analysis of strain or compression measurements together with modulus and area estimates.

In the Osterberg load test the O-cell also loads the bored pile in compression, but from the bottom. As the O-cell expands, the end bearing Q provides reaction for the side shear F, and vice versa, until reaching the capacity of one of the components or until the O-cell reaches its capacity. In the O-cell test, the end bearing and side shear components are measured separately. When one of the components reaches ultimate capacity at an O-cell load Q, the required conventional top load P to reach both side shear and end bearing capacity would have to exceed 2Q. Thus, an O-cell test load placed at, or near, the bottom of a bored pile has twice the testing effectiveness of that same load placed at the top.

Tests performed using the O-cell usually follow the ASTM

Quick Test Method D1143, although the Engineer can specify any other static method. We (LOADTEST, Inc.) measure the movements during an O-cell test by electronic gages connected to a computerized data acquisition system. Figure 2 shows schematically the basic instrumentation for an O-cell test. The total opening, or extension, of the O-cell is measured by a minimum of two linear vibrating wire displacement transducers (LVWDTs), the lower ends of which are attached to the bottom plate of the O-cell. The upward movement of the top of the O-cell is measured directly from a pair of steel telltales which extend to the top of the O-cell ('C' and 'D' in Fig. 2). These telltales also allow the measurement of the compression of the test pile. Subtracting the upward movement of the top of the O-cell from the total extension of the O-cell (as determined by the LVWDTs) provides the downward movement of the bottom plate. We can also measure the upward movement of the top of the test pile directly with dial gages mounted on a reference beam and set over the top of the test pile ('A' and 'B' in Fig. 2). Alternatively, we sometimes measure the pile compression directly with telltales and add it to the top-of-pile movement to get the top-plate movement. We also use optical or electronic leveling to check both the stability of the reference beam and the top-of-pile movements.

The reader can see from the above that the O-cell load test method provides two separate movement curves. One shows the upward movement of the pile above the O-cell vs. the O-cell loading, resisted by downward acting side shear plus the buoyant weight of the pile. The other shows the downward movement of the pile below the O-cell, resisted by end bearing plus any upward acting side shear for that part of the pile between its tip and the O-cell. The subsequent case history section of this paper will show examples of the two movement curves obtained. In fact, we compare these curves for both poor and improved construction techniques to demonstrate the importance of the construction technique.

Of course, the O-cell method has its advantages and limitations compared to conventional top-loaded tests with a surface reaction system. Interpreting the test also requires some consideration of the nature of the loading and movement vs. top loading. However, for the purposes of this paper we put aside all these considerations. Direct comparisons of poor and good construction technique O-cell test movement curves provide the best illustration of the importance of good technique.

CASE HISTORIES OF IDENTIFIED POOR CONSTRUCTION TECHNIQUE

We now present the essence of this paper in Tables 1A to 1D and Figs. 3 to 8. Tables 1A to 1D present a detailed listing of eight separate case histories, identified by a LOADTEST, Inc. Project Code Number and in order of Code Number, where the initial O-cell test appeared to identify a problem with poor construction technique. In some cases, the Contractor then corrected this technique in a parallel, otherwise nearly identical, bored pile. The second O-cell test on a similar pile showed an improvement in either the side shear or end bearing movement curve, thereby demonstrating the positive effect of the good technique. Figures 4 to 8 show the comparative movement curves from five of the eight examples.

Impact on Side Shear:

- Effect of wall roughening – Example 561, Fig. 5.
- Effect of poor concreting procedures – Example 723, Fig. 8 and Example 932
- Effect of improper use of drilling tools – Example 562, Fig. 6.
- Effect of hydrostatic imbalance – Example 711

Impact on End Bearing

- Effect of poor cleanout procedures (“dry hole”) in clay, Example 643, Fig. 7.
- Effect of poor cleanout procedures (“dry hole”) in sands/gravel/weathered rock – Examples 272 & 502, Figs. 3 & 4.
- Effect of poor cleanout procedures (stabilized hole) in weathered rock – Example 723, Fig. 8.

It should be kept in mind that the case histories presented herein represent only about 3% of the total bored piles we have tested. By and large the bored pile (drilled shaft) specialist contractors do a good job of constructing high capacity bored piles. Our experience suggests that 90-95% of bored piles are constructed properly and meet or exceed the designer’s capacity requirements.

A 133 MN (15,000 tons) O-CELL TEST

The large capacity of the O-cell test method has produced a succession of world records in load application on bored piles. In 1993, LOADTEST, Inc., in conjunction with Schmertmann & Crapps, Inc., reached 2Q = 54 MN for the Kentucky DOT on a bridge across the Ohio River at Owensboro. This increased in 1996 to 56 MN for I-93 construction in Boston for the Massachusetts DOT. Then, also in 1996, this increased to 65 MN for a Georgia DOT I-95 bridge over the St. Mary's River. The record then moved overseas to Penang, Malaysia, with a 106 MN O-cell test on a barrette. It has now returned to the USA with a February, 1997, 133 MN test of a production pier for a Florida DOT bridge across the Apalachicola River on State Route 20. Some details follow:

Water depth = 6.1 m (20 ft.)
Pile Diameter = 2.75 m. (9.0 ft.)
Pile length = 40.5 m (133 ft.)
Pile length below mudline = 31.1 m (102 ft.)
Pile socketed into limestone for 13.7 m (50 ft.)
Constructed with mineral slurry.
Instrumentation included 42 sister-bar strain gages.
Test used three 865 mm (34 in.) diameter O-cells installed on the same level, 2.1 m (7 ft.) from

bottom using a common manifold.

The shaft was inspected utilizing the FDOT's under-slurry video shaft inspection device (S.I.D.).

The O-cells were grouted in place at the end of the test.

Figure 9a shows the O-cell test movement curves obtained during this record test. These curves, as well as the magnitude of the test load, suggest good construction technique. Figure 9c shows a photo of the site and Fig. 9b the cluster of three O-cells attached to the rebar cage.

Mr. William Knight was the FDOT's geotechnical engineer for this project and test. Farmer Drilling Company constructed the tested pile, with Odebrecht Contractors of Florida the general contractor.

CONCLUSIONS

New Opportunity: O-cell testing provides separate load-movement curves for the side shear and end bearing components of the support capacity of bored piles. These separate curves provide a new opportunity for detecting and correcting poor techniques in bored pile construction.

Expanding on New Opportunity: The O-cell method almost always permits the testing of full scale bored piles or barrettes, with either side shear or end bearing reaching an ultimate load value. Testing full scale, and reaching an ultimate help greatly in detecting poor construction technique and in deciding if and how to improve the technique. In sharp contrast, conventional top-load testing has reaction limitations and the common problem of inaccuracies in evaluation strain data for load distribution. These often preclude using the overall top-load movement curve to detect poor construction technique with full-scale piles. This is especially true when the engineer limits the loading to twice the design load – then the often underestimated side shear carries the load and only small portion reaches the bottom and the soft bottom is not tested.

Poor Techniques Detected: The techniques of bored pile construction play an important part in subsequent load capacity. We have demonstrated the effects of improper hydrostatic balance, improper drilling tools, poor bottom cleaning technique, failure to roughen side walls, and poor concreting procedures.

Minor Changes Important: Some of the case histories herein show that an apparently minor change in construction technique can have a major impact on one or both components of pile capacity. In Example 932, withdrawal of casing when the static pressure of concrete inside the casing was less than the hydrostatic pressure outside the casing resulted in the loss of virtually all of the 10.7 MN (1200 tons) available side shear in the rock socket. In Example 562, using a 1.2 m (48 in.) diameter cleanout bucket, instead of a proper drilling tool, to advance a 1.2 m diameter pile shaft resulted in a loss of more than 65% of side shear.

New 133 MN Record: The new world record test of 133 MN (15,000 tons) top compressive load capacity, performed in Feb., 1997 near Apalachicola, FL, and described herein, provides an example of the very large capacities achievable with large bored piles when constructed with good technique.

ADDITIONAL COMMENTS

Occasionally Contractors, and sometimes even design engineers, initially refuse to recognize the validity of an unexpectedly low test result and look for fault with the test or the testers. However, testing another pile constructed with the same techniques or testing another pile constructed with improved construction techniques usually provides convincing evidence of the need to change technique(s).

Our experience indicates that Engineers should carefully review soil and ground water conditions before allowing “dry hole” construction, the technique preferred by many bored pile contractors. This is especially true when end bearing provides a significant portion of foundation capacity and when safety concerns preclude lowering an inspector to the bottom. It is often better, even in low permeability soils (see Example 643), to use drilling fluid, even if only water, to maintain a positive head in the hole vs. the surrounding ground water. This not only helps stabilize the sides of the shaft, but also makes bottom cleaning more effective by permitting the use of tools such as hydraulic pumps and airlifts.

This paper does not present a comprehensive list of poor bored pile construction techniques, but includes only those for which we had complete enough records to present dramatic examples. Other poor techniques encountered in our O-cell testing include dropping concrete thru water (not using a tremie), allowing a slurry to cake on sides or bottom of hole (allowing hole to remain open too long, not desanding) and providing too-stiff concrete (low slump or too long time to complete pile). The interested reader can find additional examples of O-cell testing and the serious effects of poor bored pile construction technique in the following reference:

> Schmertmann, J. H. & Hayes, J. A., 1997. “Observations from Osterberg Cell Tests of Bored Piles,” FULCRUM, The Newsletter of the Deep Foundations Institute, Winter ‘96-’97, pp.11-14.

All these examples emphasize the need for experienced Contractors, adequate supervision, and the wisdom of using technique piles to develop and test site-suitable techniques.

TABLE 1 A CASE HISTORY EXAMPLES OF THE EFFECTS OF POOR CONSTRUCTION TECHNIQUE(S) AS SHOWN BY O-CELL TEST RESULTS ON ADJACENT BORED PILES (DRILLED SHAFTS)

LOADTEST PROJECT CODE EXAMPLE	272-1		502-1	502-2
SOIL CONDITIONS (GROUND ELEV. = 0 m)	To -2.6 sand & gravel fill -6.7 loose, decomposed granite, to below –9.4 very compact weathered and fractured granite		To -7.6 loose fill -15.2 sand and sandy silt Below –22 sand and gravel with cobbles	To -8.5 loose fill -15.2 sand and sandy silt Below –22 sand and gravel with cobbles
ELEV.GWT (m)	Below –9.4		-22	-22
PILE DIAM. (m)	0.61		1.32	1.32
ELEV. BOTTOM (m)	9.4		-18.3	-18.3
CONSTRUCTION METHOD	Drilled dry and cleanout with auger only. Temp. casing and top pile at –3.2		Low clearance. Drilled with auger in 4.6 m increments. Cleaned with auger. Cage installed with 4.6 m sections	
SLURRY TYPE	None		None	None
O-CELL DIA. (mm)	535		535	535
ELEV. BOTTOM (m)	-9.25		-18.1	-18.1
NUMBER CELLS	One		One	One
TEST RESULTS				
Q_{SS} (MN) @ Δ_{SS}(mm)				
Q_{EB} (MN) @ Δ_{EB} (mm)	3.3 100	8.4 125	0.6 25	5.4 25
SEE	Fig. 3		Fig. 4	Fig. 4
CORRECTED POOR TECHNIQUE(S)	Compression of loose base soil obvious from shape of EB curve, and greatly exceeds that which might be acceptable before compressing soft bottom material to mobilize the EB.		Example illustrates great variability in success of cleaning bottom of a “dry hole” using same methods in uniform granular soil conditions above GWT	
			POOR RESULT	GOOD RESULT

TABLE 1 B CASE HISTORY EXAMPLES OF THE EFFECTS OF POOR CONSTRUCTION TECHNIQUE(S) AS SHOWN BY O-CELL TEST RESULTS ON ADJACENT BORED PILES (DRILLED SHAFTS)

LOADTEST PROJECT CODE EXAMPLE	561-DOWN	561-UP	562-1	562-2
SOIL CONDITIONS (GROUND ELEV. = 0 m)	Saprolitic clay, approx. uniform (2 parts of same bored pile)		To -10.0 water (river) -12.2 gravel -18.3 river sand -28.0 silty sand	
ELEV.GWT (m)	-11.9	-11.9	0.0	0.0
PILE DIAM. (m)	1.5	1.5	1.22	1.83
ELEV. BOTTOM (m)	-31.0	-16.0	-27.9	-28.0
CONSTRUCTION METHOD	Drilled with corebarrel type casing, no rifling (smooth wall from –16.0 to –31.0)	Drilled with corebarrel type casing, but sidewall rifled with horizontal teeth. (rough wall from –16.0 to –1.0)	Perm. Casing to –16.8. Drilling bucket but drilled too fast & did not maintain head. Casing fell under own weight.	Perm. casing to -16.2. Drilling bucket, with + head.
SLURRY TYPE	None	None	Bentonite	Bentonite
O-CELL DIAM. (mm)	865	865	865	865
ELEV. BOTTOM (m)	-15.7	-15.7	-27.4	-27.4
NUMBER CELLS	One	One	One	One
TEST RESULTS				
Q_{SS} (MN) @ Δ_{SS}(mm)	10 (incl. EB) 52	10 3	1.3 10	4.4 10
Q_{EB} (MN) @ Δ_{EB} (mm)			0.6 10	2.0 10
SEE	Fig. 5	Fig. 5	Fig. 6	Fig. 6
CORRECTED POOR TECHNIQUE(S)	Test performed to demonstrate large effect of roughening the walls on SS developed. Any differences due to depth or up/down movement would have increased 561-down SS.		•Failure to maintain + slurry head loosened sand and greatly reduced SS and EB. •Corrected by slower drilling and maintaining + head.	

TABLE 1 C CASE HISTORY EXAMPLES OF THE EFFECTS OF POOR CONSTRUCTION TECHNIQUE(S) AS SHOWN BY O-CELL TEST RESULTS ON ADJACENT BORED PILES (DRILLED SHAFTS)

LOADTEST PROJECT CODE EXAMPLE	643 –1	643 –2	711-1	711-1
SOIL CONDITIONS (GROUND ELEV. = 0m)	Medium to very stiff clay, with interbedded sand and lignite lenses. Very stiff clay without sands were encountered during the final 1.5 m excavation of 643-2		To -1.2 fill -26 residual saprolite (silts and sands)	
ELEV. GWT (m)	-3.35	-5.79	-7.6	-7.6
PILE DIAM. (m)	0.70	0.76	0.91	0.91
ELEV. BOTTOM (m)	-8.23	-16.46	-18.9	-18.9
CONSTRUCTION METHOD	Dry excavation, with temporary casing to –5.49 meters	Dry excavation, but seepage observed into bottom of excavation	Drilled to –18.9 and placed concrete with several feet of water in shaft	Drill and cased to –19.0. Placed concrete by tremie
SLURRY TYPE	None	None	None	Water
O-CELL DIAM. (mm)	535	535	865	865
ELEV. BOTTOM (m)	-8.08	-16.31	-17.4	-17.4
NUMBER CELLS	One	One	One	One
TEST RESULTS				
Q_{SS} (MN) @ Δ_{SS}(mm)			0.4 > 100	6.1 6
Q_{EB}(MN) @ Δ_{EB} (mm)	0.35 25	0.78 25		
SEE	Fig. 7	Fig. 7	No Fig.	No Fig.
CORRECTED POOR TECHNIQUE(S)	Poor bottom conditions, from imbalanced hydrostatic pressure, reduced end bearing. Reducing pile length, and therefore the imbalances, increased end bearing by 100%		Hydrostatic imbalance loosened sides and destroyed side shear. Using water and + head, with tremie concrete, corrected problem	

TABLE 1 D CASE HISTORY EXAMPLES OF THE EFFECTS OF POOR CONSTRUCTION TECHNIQUE(S) AS SHOWN BY O-CELL TEST RESULTS ON ADJACENT BORED PILES (DRILLED SHAFTS)

LOADTEST PROJECT CODE EXAMPLE	723-1	723-2	932-1	932-2
SOIL CONDITIONS (GROUND ELEV. = 0 m)	To -16.5 loose to dense sand -17.4 weathered rock -19.7 sound rock	To -12.9 sand, silt and clay -17.2 med-hard weathered mica schist	12 m overburden Shale (rock socket) Pile in socket below –12	
ELEV.GWT (m)	-2.0	-3.87	-0.8	-0.8
PILE DIAM. (m)	2.34	2.34	0.91	0.91
ELEV. BOTTOM (m)	-19.7	-17.2	-15.8	-15.8
CONSTRUCTION METHOD	Rock auger for overburden. Core barrel and chisel for rock. Temp. casing to -17.5 Cleanout bucket Concrete w/out retarder	(same) Temp. casing to -13.5 + Hydraulic pump Concrete with retarder	Drilled to –12 Install casing. Drill socket to –15.8. Extend casing to –15.5 Place concrete and O-cell to –12. Pull casing.	Same to –12. Drill socket to -15.8 maintaining + water head in casing. Place O-cell and concrete by tremie to –12.
SLURRY TYPE	Soil/Water Mix	Bentonite	None	Water
O-CELL DIAM. (mm)	535	535	535	535
ELEV. BOTTOM (m)	-18.8	-16.7	15.5	15.5
NUMBER CELLS	Three	Three	One	One
TEST RESULTS				
Q_{SS} (MN) @ Δ_{SS}(mm)	3.0 5	15.9 5	0.4 100	10.7 32
Q_{EB} (MN) @ Δ_{EB} (mm)	0.7 3	19.0 3		
SEE	Fig. 8	Fig. 8	No Fig.	No Fig.
CORRECTED POOR TECHNIQUE(S)	•Poor cleanout & technique using soil slurry reduced EB. Improved both. •Concrete flash setting before casing pulled gave poor bond for SS. Retarder, raised casing and bentonite slurry improved bond.		Pulling casing without excess water/concrete pressure caused sides to collapse towards concrete, destroying side shear. Maintaining positive head of water, plus using tremie corrected problem	

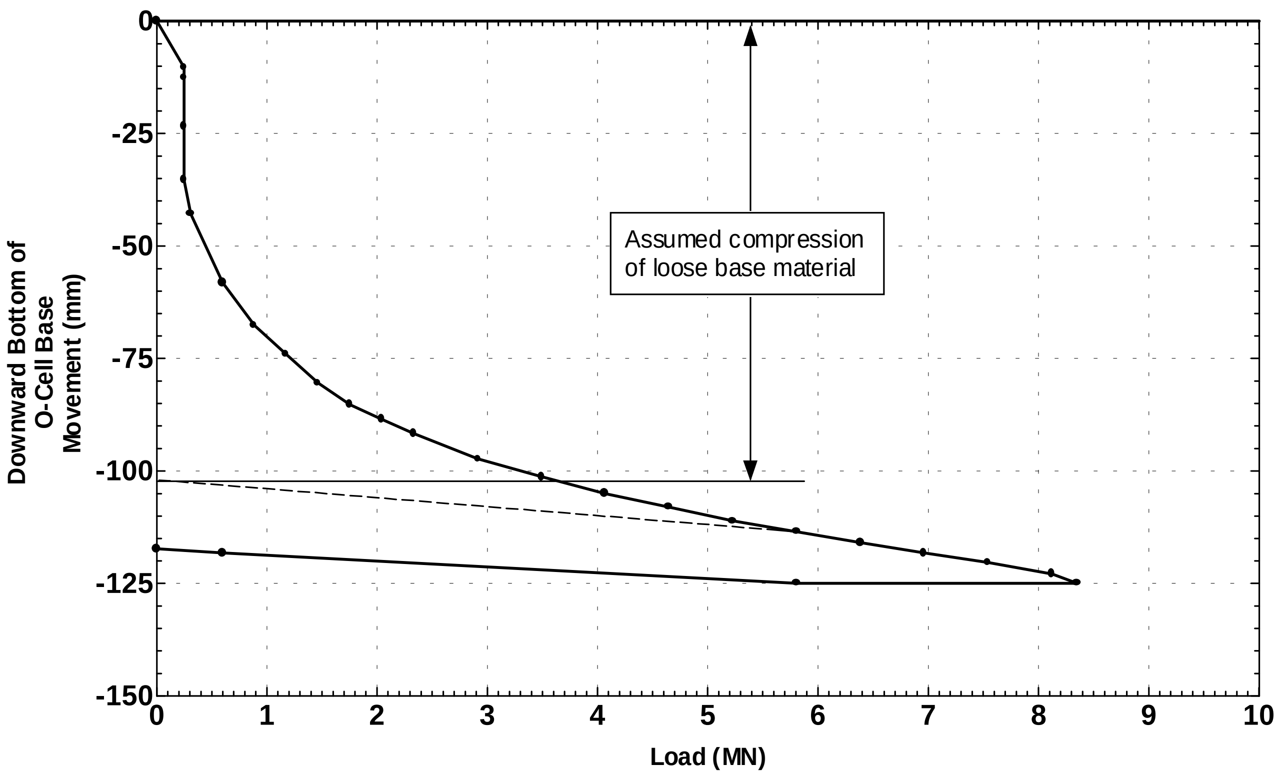

Fig. 3 - Example 272, effect of poor cleanout procedures ("dry hole") in weathered rock

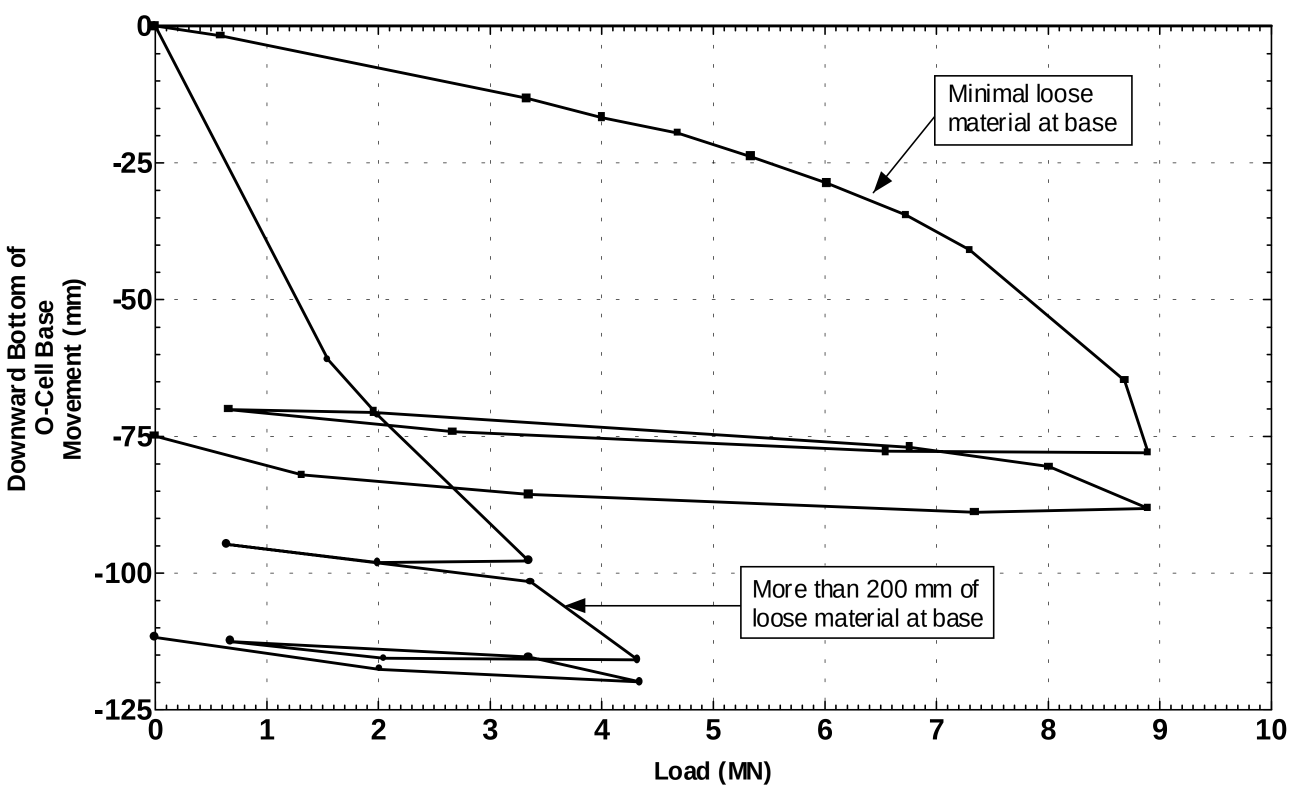

Fig. 4 - Example 502, effect of poor cleanout ("dry hole") in sands, gravel

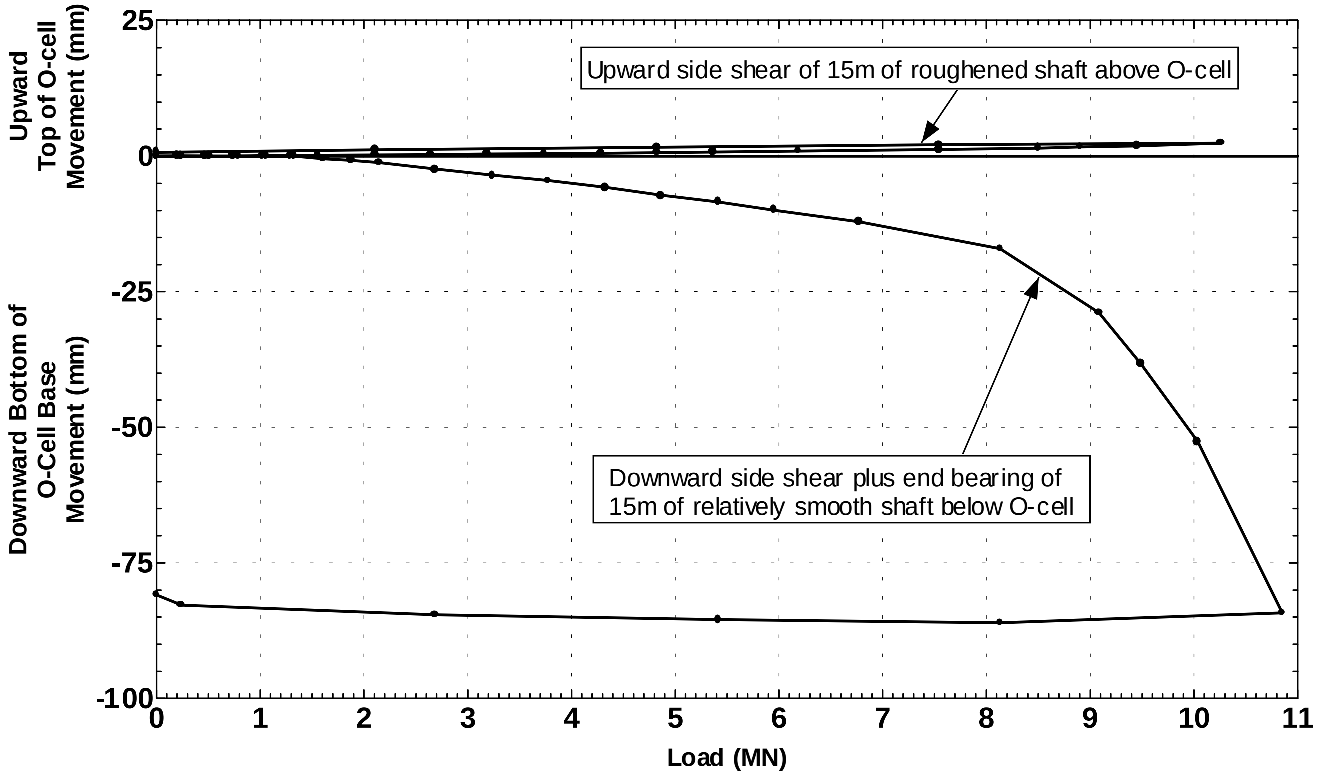

Fig. 5 - Example 561, effect of wall roughening

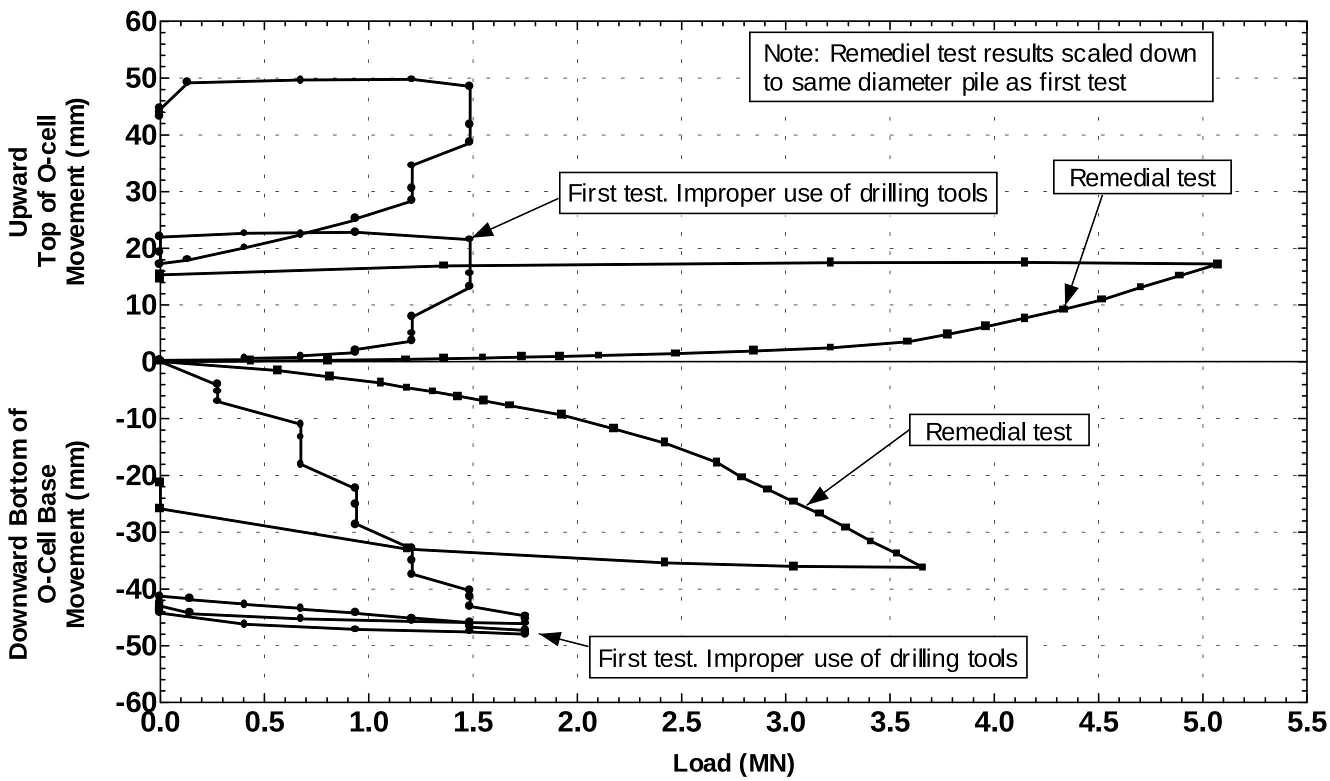

Fig. 6 - Example 562, improper use of drilling tools

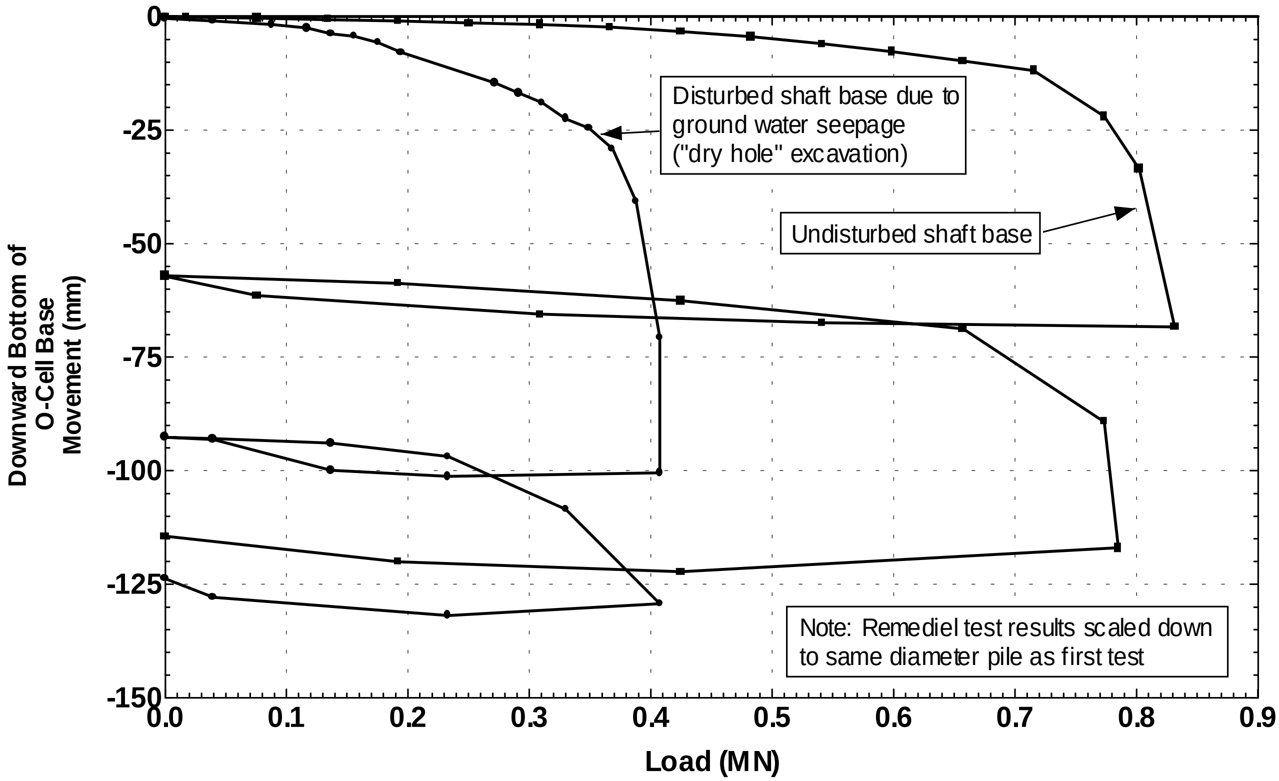

Fig. 7 - Example 643, effect of poor cleanout procedures ("dry hole") in clay

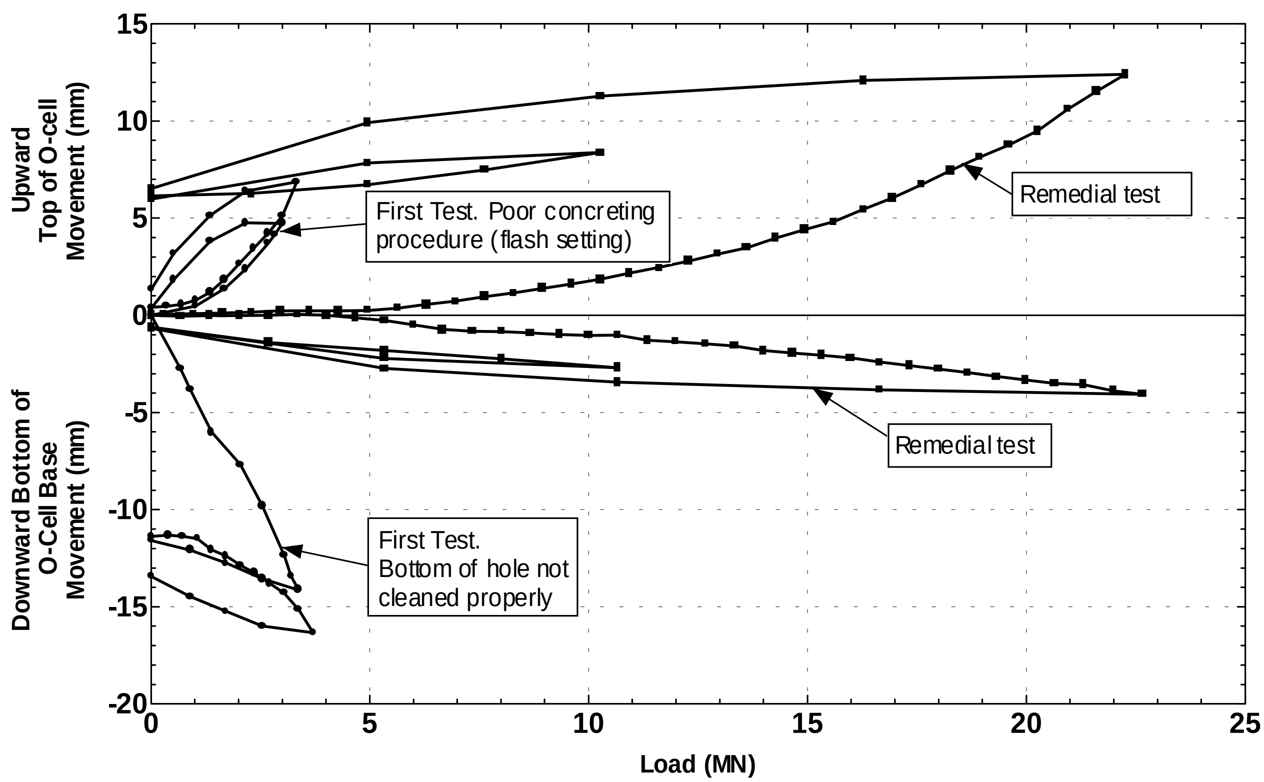

Fig. 8 - Example 723, effect of poor cleanout procedures in weathered rock (EB) and effect of poor concreting procedures (SS)