CALIBRATION OF PVR METHOD

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Expansive clays in the active zone can cause major damages to foundations, structures, pipelines and other civil infrastructures that are supported on it due to fluctuations in moisture content. The commonly accepted standard of practice for geotechnical engineers practicing in the greater Houston area, not all, is to compute the potential vertical rise (PVR) using Tex-124-E to evaluate potential heave, and then make ground improvements to improve the PVR to an acceptable risk (typically 1 to 2 inches).

While Tex-124-E is commonly used by practicing geotechnical engineers, there has been little published data regarding the accuracy of the Tex-124-E calculations. The author has been the engineer of record for many geotechnical forensic studies where structures have been damaged due to heaving soil. However, comparisons of measured and predicted heave are difficult due to the following reasons:

- A stable benchmark is never constructed to monitor post-construction movements.
- Heave of the floor slab, and sometimes footings, can make the selection of stable areas on the floor slab for evaluation of heave difficult.
- Underreamed piers (common foundation type in the greater Houston area) lock down the perimeter of the building and interior columns somewhat restraining heave. The resulting diaphragm action of the floor slab puts a vertical pressure on the subgrade, and this pressure reduces swelling of the clays (cannot measure free swell).

The author has been the engineer of record for many geotechnical forensic studies where settlement of foundations has occurred due to moisture demand of trees. Settlement is due to a reduction of moisture causing internal suction which pulls the microscopic clay platelets together resulting in shrinkage. Shrinkage is the opposite of heave where the addition of water forces the clay platelets apart resulting in swelling. Jean Louis Briaud (2003) discusses that the path of the moisture and volume changes are practically linear between the shrinkage and swell limits. In other words, if the ground surface settles in the summer because of shrinkage due to moisture losses, the surface should return to its initial elevation in the winter when it regains the moisture that it lost. There may be extremes where this logic is not 100% applicable because the amount of swelling that occurs is affected by the confining pressure. The conclusions in this study assume that the same quantity of ground movements that occur due to drying would also occur due to swelling (**the PVR and settlement are equal and the terms will be used interchangeably in this report**).

Comparison of measured and predicted settlement is easier due to the following reasons:

- In areas beyond the influence of the trees, the ground is typically stable thus providing a reference point, unless heave has also occurred.
- The underreamed piers beyond the influence of trees act somewhat as an embedded stable post construction benchmark. However, some settlement of the footings would have occurred due to structural loads.
- Soil borings can be drilled in the areas of settlement, and in stable areas well beyond the influence of trees to provide post construction and end of construction samples. Moisture content, swell, and Atterberg limit tests can be performed on soil samples to evaluate post construction and end of construction soil properties.
- The depth of the active zone can be determined by plotting the post construction and end of construction moisture contents, and from soil suction tests.

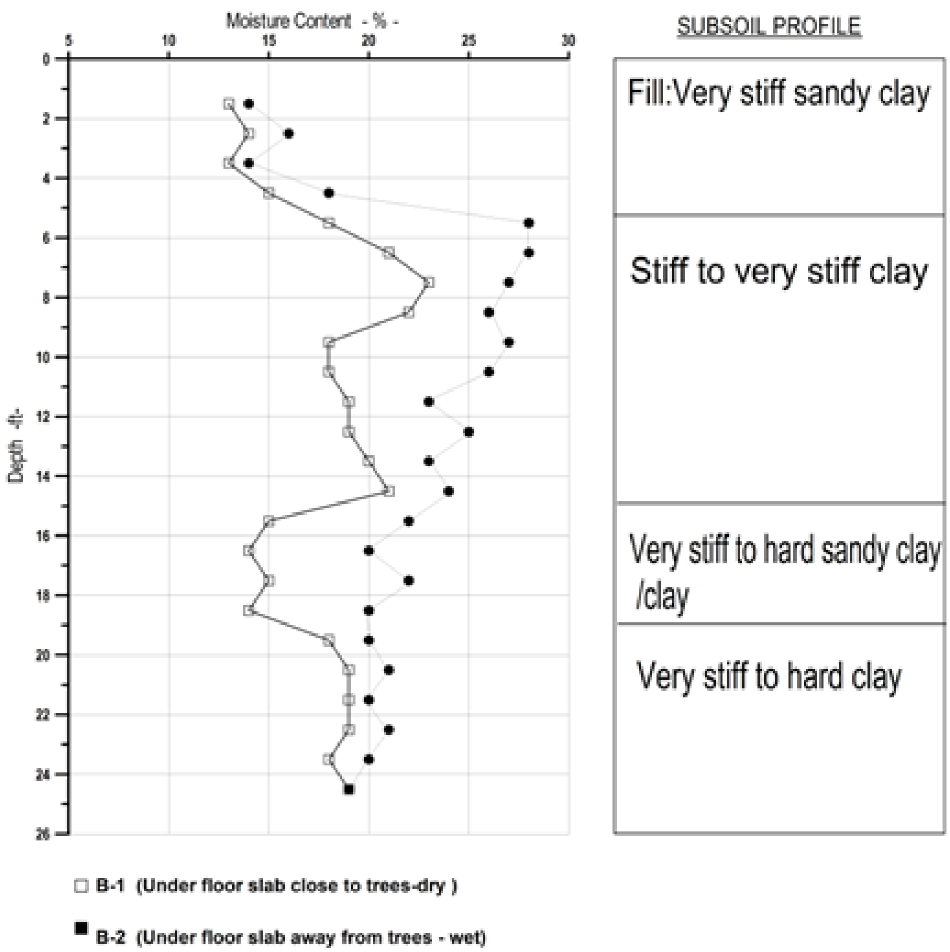

Figure 1: Subsoil Moisture/Depth Profile

Shown on Figure 1 below is a graph of the moisture profile at a site in the Westchase area of Houston demonstrating the value of the moisture data typically collected in a geotechnical forensic study.

The author has tabulated the subsoil data and the PVR calculations for 8 well documented sites in Houston on Beaumont clay (attached at end of Abstract). The Tex-124-E procedure is based on the research performed by Chester McDowell in the 1940's and 1950's, and there have only been minor modifications since then. The PVR calculations assume swell starting at McDowell's dry moisture condition to 100% saturation [PVR (3)], from McDowell's dry to wet moisture condition [PVR (4)], and from Mc Dowell's estimated moisture conditions for each soil layer that existed at the end of construction to 100% saturation [PVR (5)]. The measured total settlement of the ground surface is tabulated for comparison purposes. It should be noted that construction tolerances are commonly ±½ inch, and could be greater for projects where poor quality control occurred.

Analysis of the data shows that there is very poor correlation between the predicted settlement that occurs between McDowell's relative moisture conditions for each soil layer that existed at the end of the construction (moisture below stable areas of the floor slab) to dry conditions that existed at the time of the forensic study (location of maximum settlement). Also, there is poor correlation between the predicted settlement that assumes moisture changes occur between McDowells' optimum and dry conditions.

There is reasonable to good correlation at 8 of the sites between predicted settlement from 100% saturation to McDowell's dry conditions. However, the predicted settlement is about ½ of the measured value at the two sites where 8 to 8½ inches of settlement occurred.

McDowell's classification of the relative moisture condition (optimum/average/dry) poorly fits the data for Beaumont clay as found by Tand & Vipulanandan (2012). About ⅓ of the moisture contents on Figure 1 of that report fall below McDowell's dry moisture classification ($w = .2LL +9$) meaning that the measured moisture contents in Tand's data base are considerably lower than used in the Tex-124-E procedure.

This study finds that use of the PVR method can result in unconservative predictions of PVR when swell occurs from dry conditions. Such events commonly occur in Houston today when mature trees are removed at the site of new construction, and buildings are built above the area influenced by moisture demand of the trees. Improvements need to be made to adjust McDowell's curves to better fit the data, or to develop better methods of analysis.

REFERENCES

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SITE 1 (UPTOWN KIRBY AREA)
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-4	Fill: very stiff to hard clay	57	41	
4-12	Very stiff to hard clay	63	47	
12-17	Very stiff to hard sandy clay	40	26	
17-25	Very stiff to hard clay	72	48	(22')

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR(3) (dry)	PVR (4) (wet-dry)	PVR (5) McDowell
4.9	6.6	4.7	2.8	0.1

SITE 2 (WESTCHASE AREA)
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-4	Fill: very stiff sandy clay	40	26	
4-15	Very stiff clay	68	51	
15-20	Very stiff sandy clay/clay	49	36	
20-25	Very stiff clay	57	41	(25')

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR (3) (dry)	PVR (4) (wet-dry)	PVR (5) McDowell
4.2	4.5	4.5	3.0	0.4

Notes:

(1) Estimated from elevation contours (±½ inch) plus the void found below the slab
(2) Volumetric swell at point of maximum settlement minus volumetric swell at control point not adjusted for ratio of vertical/volumetric swell
(3) Assumes swell from McDowell dry conditions to 100% saturation
(4) Assumes swell from McDowell wet conditions to dry conditions
(5) Assumes swell from McDowell end of construction moisture conditions to dry conditions

SITE 3 (BELLAIRE AREA
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-4	Fill: very stiff to hard sandy clay	46	33	
4-15	Very stiff to hard sandy clay/clay	56	41	
15-25	Stiff to very stiff sandy clay	39	25	(18')

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR (3) (dry)	PVR (4) (wet-dry)	PVR (5) McDowell
3.5	3.0	3.5	2.0	0.1

SITE 4 (SOUTHWEST HOUSTON)
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-4	Fill: very stiff clay/sandy clay	50	34	
4-12	Very stiff clay	83	57	
12-20	Very stiff clay	75	51	(19')

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR (3) (dry)	PVR (4) (wet-dry)	PVR (5) McDowell
3.0	5.9	5.3	3.0	2.6

Notes:

(6) Estimated from elevation contours (±½ inch) plus the void found below the slab
(7) Volumetric swell at point of maximum settlement minus volumetric swell at control point not adjusted for ratio of vertical/volumetric swell
(8) Assumes swell from McDowell dry conditions to 100% saturation
(9) Assumes swell from McDowell wet conditions to dry conditions
(10) Assumes swell from McDowell end of construction moisture conditions to dry conditions

SITE 5 KINGWOOD AREA
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-2	Fill: very stiff sandy clay	28	13	
2-8	Very stiff to hard clay	58	34	
8-15	Very stiff to hard sandy clay	43	30	
8-24	Very stiff clay	62	43	(22’)

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR (3) (dry)	PVR (4) (wet-dry)	PVR (5) McDowell
3.5	2.8	2.8	1.9	0.3

SITE 6 (SUGAR LAND)
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-3	Fill: very stiff to hard clay	75	52	
3-6	Very stiff to hard clay	85	54	
6-10	Very stiff clay	54	36	
10-12	Stiff to very stiff clay	69	45	(10’)

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR (3) (dry)	PVR (4) (wet)	PVR (5) McDowell
2.8	5.7	3.7	1.9	1.2

Notes:

(11) Estimated from elevation contours (±½ inch) plus the void found below the slab
(12) Volumetric swell at point of maximum settlement minus volumetric swell at control point not adjusted for ratio of vertical/volumetric swell
(13) Assumes swell from McDowell dry conditions to 100% saturation
(14) Assumes swell from McDowell wet conditions to dry conditions
(15) Assumes swell from McDowell end of construction moisture conditions to dry conditions

SITE 7 (CLEAR LAKE AREA)
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-4	Fill: very stiff sandy clay	39	21	
4-15	Very stiff to hard clay	71	47	
15-25	Very stiff clay	71	47	(25')

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR (3) (dry)	PVR (4) (wet-dry)	PVR (5) McDowell
8.0	—	4.6	3.1	1.8

SITE 8 (ASTRODOME AREA)
SUBSOIL PROFILE

Depth (ft.)	Soil Description	Liquid Limit (%)	Plasticity Index (%)	Depth of Active Zone
0-4	Fill: very stiff sandy clay	38	23	
4-10	Very stiff to hard clay	97	70	
10-20	Very stiff clay	85	58	(20')

MEASURED/COMPUTED SETTLEMENT (Inches)

Measured (1)	Unadjusted (2) Swell Tests	PVR (3) (dry)	PVR (4) (wet-dry)	PVR (5) McDowell
8.5	—	4.6	2.0	1.0

Notes:

(16) Estimated from elevation contours (±½ inch) plus the void found below the slab

(17) Volumetric swell at point of maximum settlement minus volumetric swell at control point not adjusted for ratio of vertical/volumetric swell

(18) Assumes swell from McDowell dry conditions to 100% saturation

(19) Assumes swell from McDowell wet conditions to dry conditions

(20) Assumes swell from McDowell end of construction moisture conditions to dry conditions