Experience of a Large Scale Unintentionally Long Surcharge on Organic Soils

Ying Liu, Ph.D., P.E., Senior Engineer, Group Delta Consultants, Inc., 370 Amapola Ave., Suite 212, Torrance, CA. Email: yingl@groupdelta.com

Michael D. Reader, G.E., CEO, Group Delta Consultants, Inc. Email: miker@groupdelta.com

Abstract

A large urban infill development in the City of Los Angeles near the Pacific Ocean provided unique opportunity for gaining insight into to the behavior of soft clays with high organic content under large scale surcharge program for extended period of time. Long term surcharge settlement monitoring data and pre- and post- surcharge investigation offered extensive amount of data for analyzing and understanding the contributing factors of shear strength gains including the thickness and depth of soft clays, surcharge height and duration, drainage path for pore water pressure dissipation, and soil plasticity index. Continuous soil coring and Cone Penetration tests have been conducted to investigate the organic soils. Possible preliminary correlation could be formed to relate soil shear strength increase with surcharge height, insitu overburden pressure, and soil plasticity. Long term surcharge settlement monitoring also provided a unique opportunity to assess the magnitude and actual rate of secondary consolidation. The observed time rate consolidation was compared with theoretical one dimensional time rate consolidation calculations. Reasons for any discrepancy observed between actual time rate consolidation and theoretical calculation were explored to identify major causative factors that needs careful evaluation for predicting time rates for similar projects. Based on actual surcharge settlement data, additional surcharge height and time frame were established for mitigating additional secondary settlements within the life expectancy of the proposed development.

Introduction

Playa Vista Development – the former Hughes Airport is the first new community under development on the Westside of Los Angeles, California in more than 50 years. It is one of the largest urban infill developments in the history of United States. Situated just north of the Los Angeles International Airport, approximately 1.7 miles from the Pacific Ocean, it encompasses approximately 1,100 acres, featuring a ongoing development consisting of residential, commercial, retail and open space. Development of this site requires that the existing site grade be raised from approx. El. + 5 to + 10 feet to approx. El. + 20 to 28 feet. Development of this site was complicated by poor geotechnical and environmental conditions such as high groundwater, thick layers of soft, highly compressible organic soils, moderately high ground acceleration, presence of liquefiable soils, and the presence of methane. Foundation solutions included preloading the site with surcharge fill, adopting driven piles foundation and / or Auger-Pressure-Grout-Displacement (APGD) piles. Selection of foundation system was driven by geotechnical conditions as well as financial considerations, construction time, environmental concerns (such as methane, noise, vibrations, etc.). Where surcharge fill was available and construction time permits, as the result of prolonged environmental impact study, preloading the site by placing surcharge fill has been determined to be the most economical solution.

The large scale of the surcharge program for development of portions of this site provided unique opportunities for gaining insight into to the behavior of soft organic clays under prolonged loading. Long term surcharge settlement monitoring data and pre- and post- surcharge investigations offered extensive amounts of data for analyzing and understanding the contributing factors of shear strength gains including the thickness and depth of soft clays, surcharge height and duration, drainage path for pore water pressure dissipation, and soil plasticity index.

Geotechnical Conditions

Figure 1 shows the general site plan of Playa Vista Urban Development. This paper presents the study of Phase II development, which features a pan-shaped parcel measuring approximately 100 acres. Due to the prolonged Environmental Impact Study, preloading this area by placing surcharge fill was determined to be the most economical solution for site improvement. In particular, surcharge fill on lots 35-48, surcharge fill was left in place from September 2006 to March 2010 for a period of 42 months, which provided a unique opportunity for studying the behavior of soft organic clays under long term surcharging.

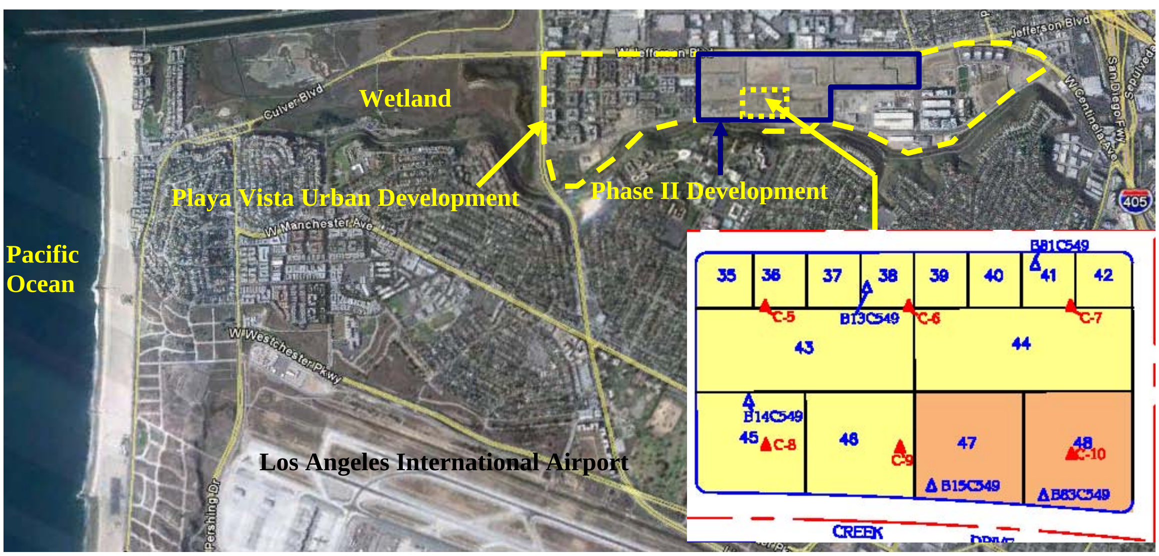


Figure 1: Site plan of Playa Vista Urban Development; Locations of pre- (open triangle) and post- (solid triangle) surcharge CPTs; and lot numbers for lots 35-48.

The subsurface soils at this site consists of soft to stiff, moderately to highly compressible natural clay soils interbedded with medium dense sands. Very dense gravelly sands are in general encountered at El. -35 feet to -40 feet, approximately 45 to 50 feet below existing grade. A typical geologic cross-section (through lots 35-48) is shown in Figure 2.

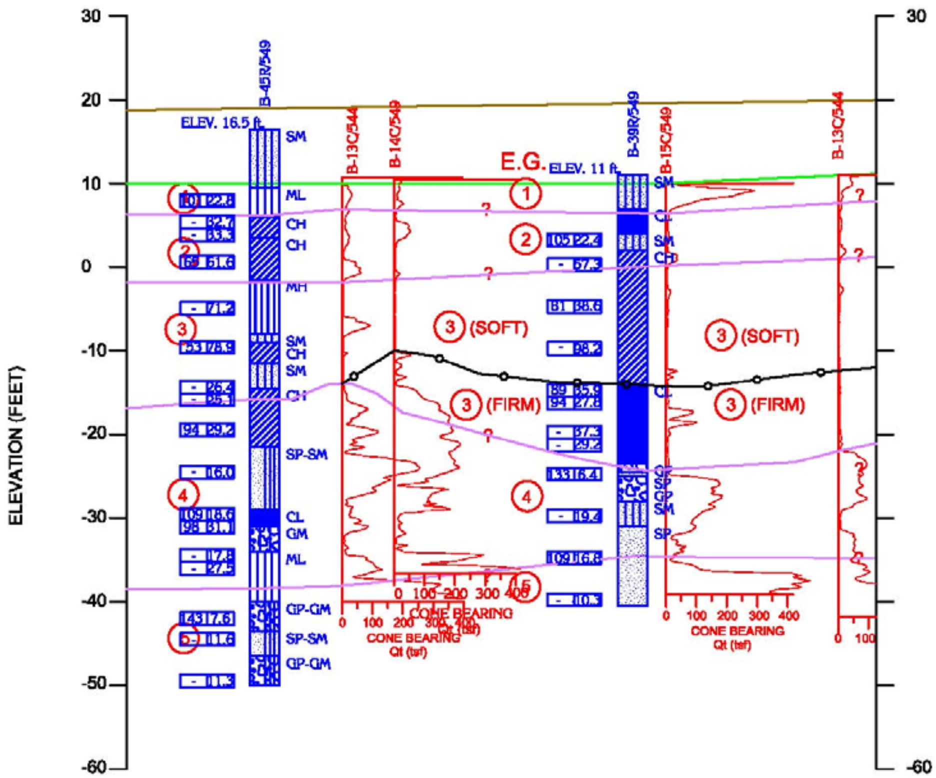
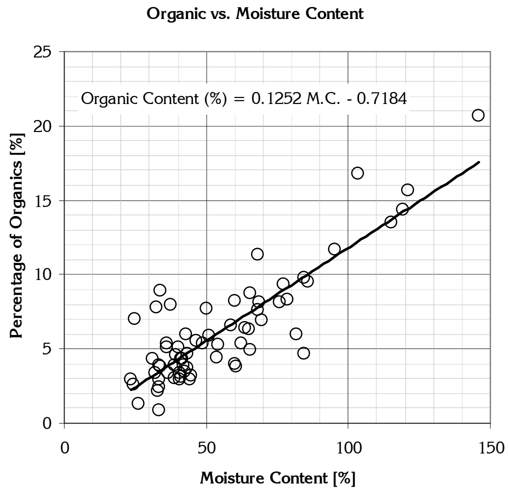


Figure 2: A typical geologic cross-section through lots 35-48

As shown in Figure 2, a layer of soft to firm, normally to slightly overconsolidated, highly compressible clays are present at this site with thickness of up to 20 feet. The undrained shear strength of this clay, interpreted from cone penetration tests and pocket penetrometer readings, are often less than 750 psf.

Organic Soil Investigation – By Direct Push Sampling

Fifty one direct push (Geoprobe) sampling and 21 CPT soundings were conducted to investigate the organic soils. Most of the clays and silts at this site have moisture content ranging 30% to 90% with corresponding organic content ranging from 2% to 10%. Limited lenses of highly organic soils have been identified at various depths in several borings. These high organic soils are characterized by high moisture content (above 90%) and low dry density (below 60 pcf). For example, a lens of soft organic clay up to 6 inches thick with moisture content greater than 200% was identified at 18.5 feet depth in one boring on lot 45. Organic content testing on this sample indicated the highest measured organic content of 20.7%. The high moisture content, highly organic soils are characterized by high compression index, in the range of 20 to 40 percent. A plot showing moisture content vs. compression index is shown in Figure 3.



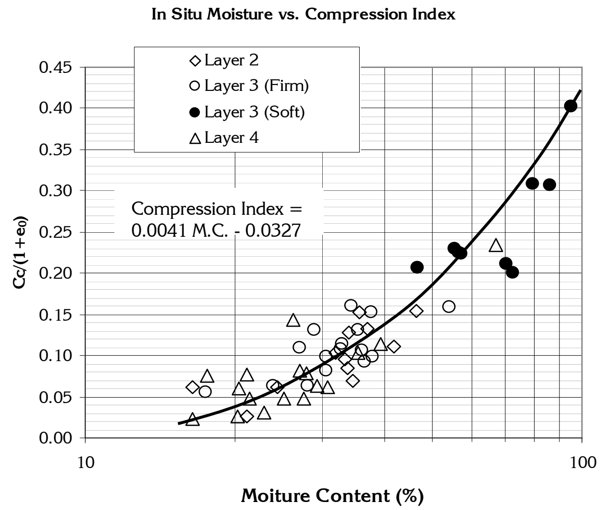


Figure 3: Possible correlation of moisture content vs. organic contents and compression index.

Effect of High Organic Soils on Foundation Settlements

Design of shallow foundations on organic soils must account for not only the settlement due to primary consolidation, but also future settlement due to secondary consolidation. Data presented by Mesri et. al (1997), and Mesri (2001) on primary and secondary compression of Peat and normally consolidated organic clays indicates that the secondary compression coefficient $C_\alpha / (1+\varepsilon_0)$ is related to $C_c / (1+\varepsilon_0)$ and the ratio of C_α / C_c for various soils varies as follows:

Table 1 Ratio of $C\alpha/C_c$ from Mesri et al. (1997 and 2001)

Material	Cα/Cc
Granular Soil	0.02 ± 0.01
Shale and Mudstone	0.03 ± 0.01
Inorganic Clays / Silts	0.04 ± 0.01
Organic Clays / Silts	0.05 ± 0.01
Peat and Muskeg	0.06 ± 0.01

Further, the $C_c / (1+\varepsilon_0)$ for peat can be high (0.3 to 0.6) for moisture contents in the range of 200% to 500% or higher as compared to organic clays with moisture contents of 60-200% (0.15 to 0.3).

The soils at this site generally have a moisture content around 40-60% with isolated thin layers with moisture contents between 60 and 145%. In general, the high moisture content soils have $C_c / (1+\varepsilon_0)$ in the range of 0.2 to 0.4 and a coefficient of secondary compression $C\ \alpha / (1+\varepsilon_0)$ of 0.01 to 0.02. The high moisture content soils (moisture content >100%) may be represented by twice the thickness of normal soft soils with moisture content of 60%. For example, a 6-in. thick layer of 150% moisture content organic clay will cause settlement similar to a 1-ft thick layer of clay with a moisture content of 60%.

Based on field exploration, laboratory testing results, and published correlations, a soil model for predicting primary and secondary compression is developed (Table 2).

Table 2 Soil Model for Settlement Prediction

Depth (ft)	Moisture Content, %	Cc / (1+e0)	Cα / (1+e0) (NAVFAC)	Cα / (1+e0) (Mesri)
0-10	35	0.05	0.003-0.01	0.0035
10-20	55	0.15	0.007-0.015	0.0075
20-21	120	0.3	0.01-0.024	0.015
22-30	35	0.05	0.003-0.01	0.0035

Based on this soil model, if this site is to be raised to the proposed final grade at El. +28 feet from current grade of El. +10 feet, approximately 16 inches of primary consolidation settlement was predicted. If projected to 30 years, the magnitude of secondary settlement will range from 3 to 9 inches. Therefore, a surcharge program was implemented to complete the majority of the primary settlement and to mitigate any possible secondary settlement.

Accidental Surcharge on Lots 35-48 – Undrained Shear Strength

To raise the site grade to proposed finish grade, and to provide some surcharge for future at-grade residential buildings, compacted fill and surcharge fill was placed on this site in September 2006 at the height of the residential development market. The elevation of the top of surcharge was at El. +35 feet. The existing site grade was at approximately El. +10 feet; therefore, a total of 25 feet of soil was placed over this site. Past experience had been that if no additional settlement was measured within a period of 30 days, the surcharge settlement was considered to be completed and the surcharge could be removed and the construction could begin. This was usually achieved within 6 months to one year. However, due to delays of environmental impact study and then the collapse of the housing market in 2008, surcharge fill on Lots 35-48 was unintentionally left in place and surcharge settlement monitoring monuments were protected for almost 5 years as of this date. New investigations and planning was finally started in September of 2010; at which time the 25 feet of surcharge soil have been left in place on lots 35-48 for 4 years. This provided a unique opportunity for gaining some insight into shear strength gains and long term settlement behavior for the soft clays at lots 35-48.

There are a total of 6 post-surcharge CPTs and 5 pre-surcharge CPTs been performed on Lots 35-48 (Fig. 1). The undrained shear strength of clay soils interpreted from post-surcharge CPTs was compared with that of the pre-surcharge CPTs. A Nk factor of 15 was used in interpretation of undrained shear strength from both pre- and post- surcharge CPTs. The comparisons are shown in Figure 4.

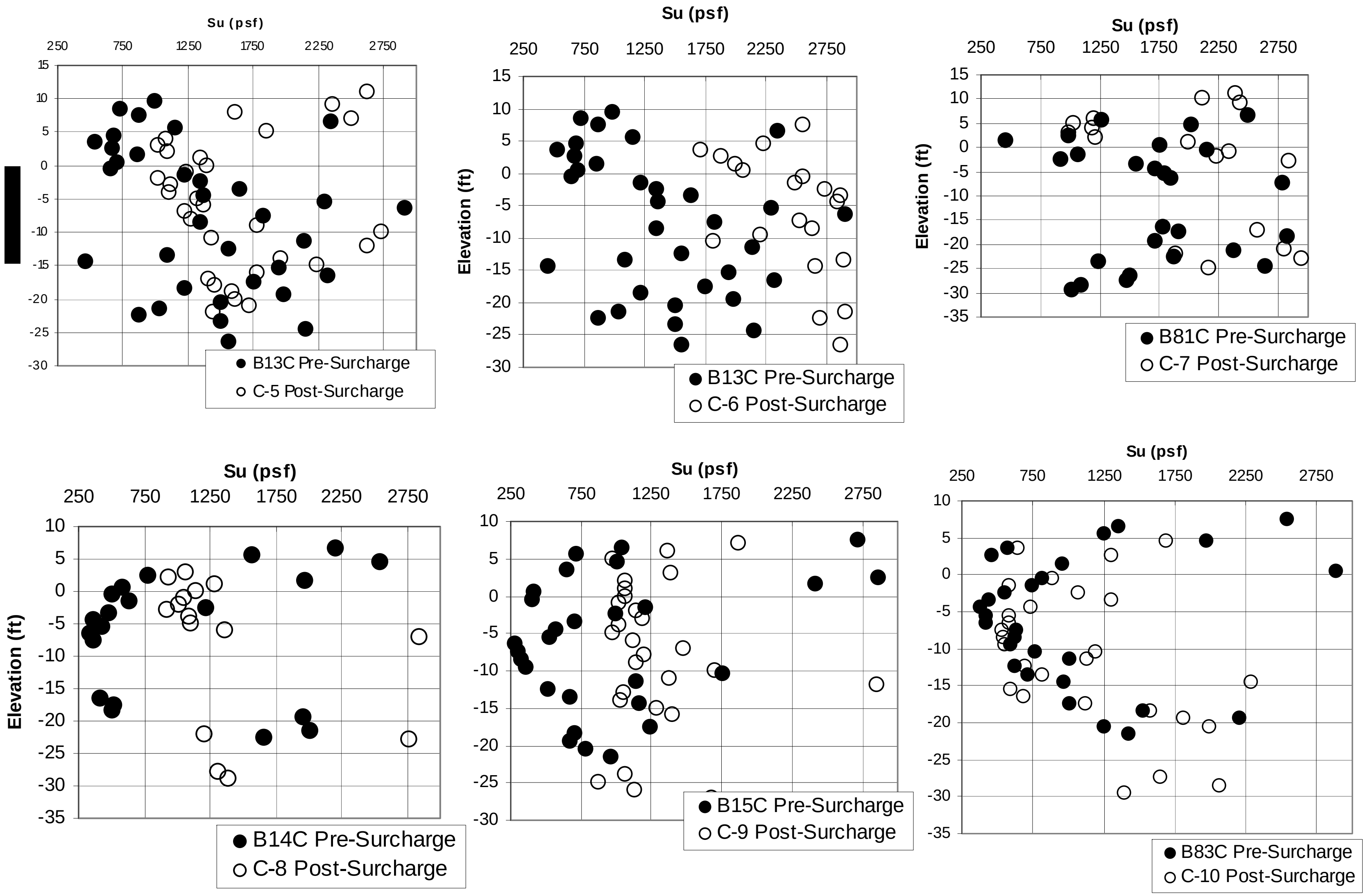


Figure 4: Comparison of undrained shear strength at pre- and post- surcharge stage

From Figure 4, it is observed that significant gain in undrained shear strength has been achieved in lots 35 to 46, which is represented by post-surcharge CPTs of C5 to C9 and pre-surcharge CPTs of B13C549, B14C549, B15C549 and B81C549. In general, the post surcharge CPTs indicated that through the implementation and completion of surcharge program, the soft clays of Su of 250 psf to less than 1,000 psf have been improved to Su of greater than 1,000 psf.

However, in Lots 47 to 48, as represented by pre-surcharge CPT B15C549 , B83C549 and post-surcharge CPT C10, even though the improvement is obvious since the accumulated 5-foot thick layer of soft clays with Su of 250 psf to 500 psf measured at pre-surcharge state has in general been improved to Su of greater than 500 psf, there are still significant thickness of soft clays (accumulated thickness of 13 feet) with Su of 500 psf to 1,000 psf in the post-surcharge state.

To understand the phenomena that under the same surcharge pressure, for the same surcharge duration, and in general in the same area, the causes of this significant differences in post-surcharge undrained shear strengths between lots 35 to 46 and lots 47 to 48, it is necessary to examine the subsurface soil condition prior to the implementation of surcharge. Figure 5 provides the summary plot of pre-surcharge state Su of lots 35 to 46 and lots 47 to 48. Note that unbalanced numbers of pre-surcharge CPTs for lots 35-46 and lots 47-48. In this plot, three CPTs are plotted for lots 35-46 and two CPTs are plotted for lots 47-48.

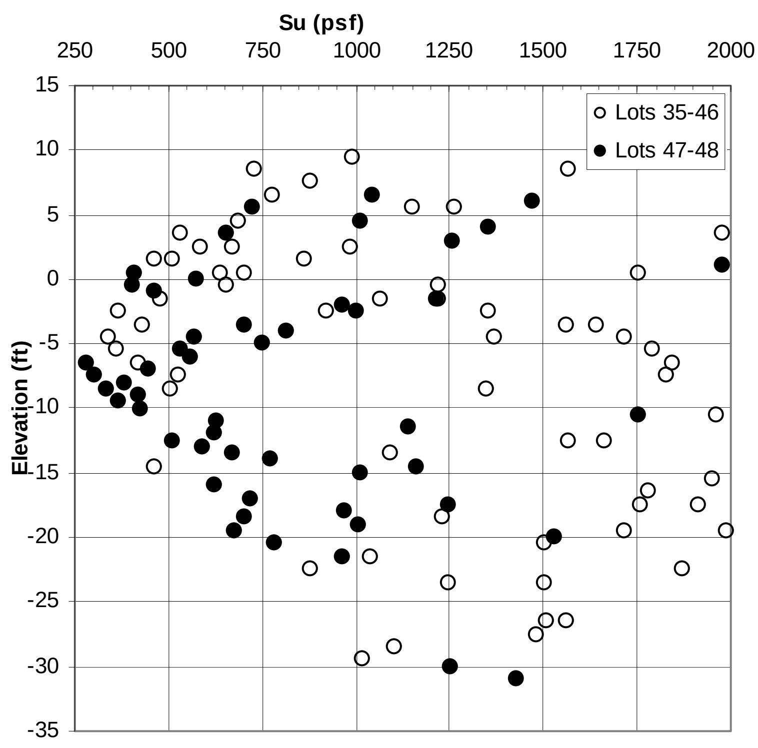


Figure 5: Comparison of pre-surcharge Su of Lots 35-46 and Lots 47-48 (note that the soft clay was deeper and thicker at lots 47-48).

It is observed from Fig. 5 and by examining individual CPT interpretation in the pre-surcharge state, the thickness of soft clays with Su of 250 psf to less than 1,000 psf for lots 35-46 ranges from 3 feet to 12 feet, which is much thinner than that of Lots 47-48 where the thickness of similar soft clay is about 17 feet. Further observation revealed that the soft clays at lots 35-46 exist at much shallower depths (the bottom elevation of this soft clay ranges from El. -0.5 feet to El. -8.5 feet, whereas, the soft clays at lots 47-48 extended to much deep depths (El. -18 feet to El. -21.5 feet). The differences in thickness and bottom elevations of the soft clay in lots 35-46 and lots 47-48 have the following impacts in terms of site improvement by surcharging:

- For lots 35-46, since the soft clay exists at a much shallower depth, with regard to the insitu effective stress, soft clays at lots 35-46 has been experiencing higher surcharge pressure compared with that of lots 47-48 from vertical pressure distribution standpoint;

- Due to the closeness to ground surface, the upper drainage path for dissipation of excess pore water pressure at lots 35-46 has been shorter compared with that of lots 47-48;

- And, the thickness of soft clay at lots 47-48 is much thicker than that of lots 35-46 which itself requires higher surcharge or longer duration to gain similar improvements.

To have a collective picture of site improvement for lots 35 to 48 as a whole, we have plotted all of the pre-surcharge Su and post-surcharge Su on a single plot (Figure 6). It is obvious that the pre-surcharge state has a significant number points indicating Su of less than 500 psf, whereas all of the Su of the post-surcharge state are greater than 500 psf. Nearly half of the Su of pre-surcharge state are less than 1,000 psf whereas the majority of Su of post-surcharge state are close or greater than 1,000 psf. The few points of post-surcharge state that fell below 1,000 psf are from lots 47-48 where the soft clays are thicker (17 feet) and extend to deeper depth, as discussed earlier in this paper.

Also, to obtain a statistical understanding of site improvement in terms of Su, we plotted a histogram of the pre- and post-surcharge Su (Figure 7). It is observed that the mean Su of pre-surcharge state (Su is limited to less than 3,000 psf for this comparison) is 1,253 psf, whereas the Su of the post-surcharge state is 1,600 psf. The modal value (defined as the highest number of occurance) of Su for the pre-surcharge state is 750 psf, whereas that of the post-surcharge state is 1,250 psf. The strength gain is 346 psf for the mean value and 500 psf for the modal value which corresponds to 12 percent to 17 percent of applied surcharge pressure.

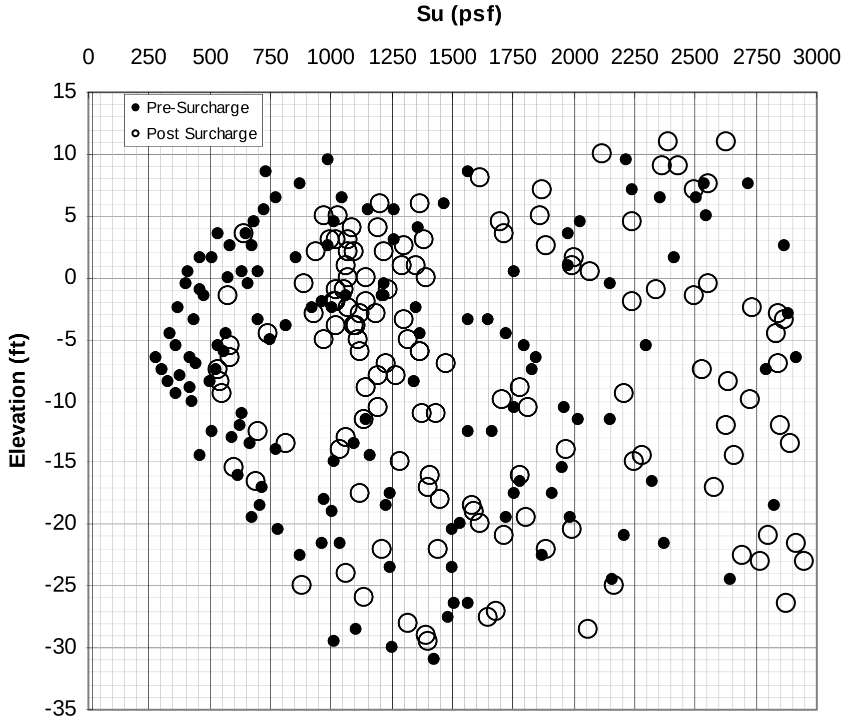


Figure 6: Summary Plot of Pre-Surcharge and Post-Surcharge Su of Lots 35-48

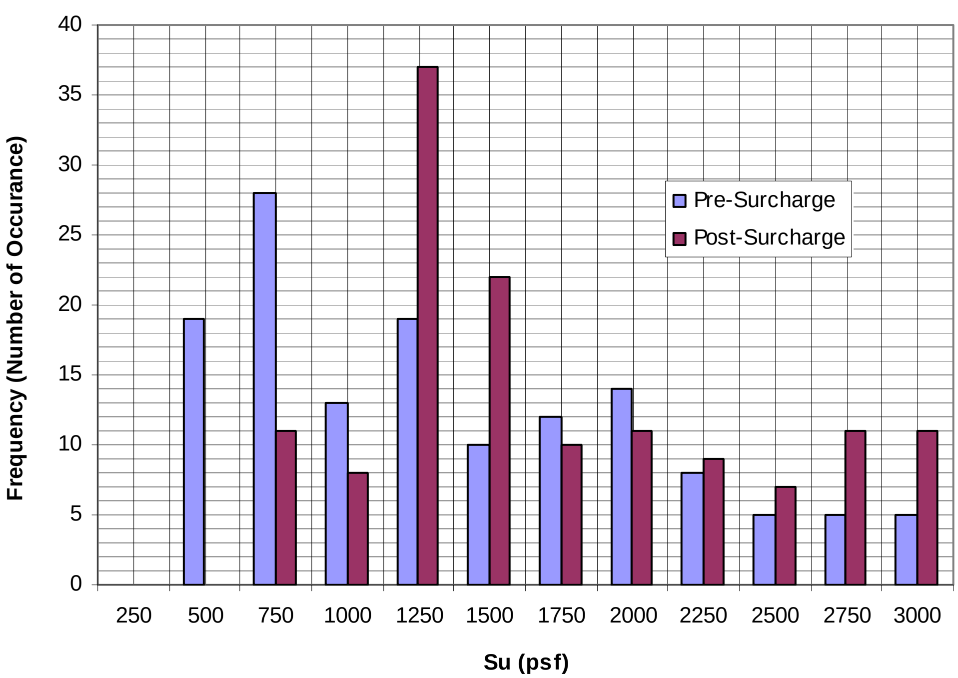


Figure 7: Histogram of Pre-Surcharge and Post-Surcharge Su of Lots 35-48

In conclusion, for lots 35 to 46, comparison of pre- and post- surcharge Su indicates that for soft clays ranging from 3 feet to 12 feet with bottom El. at -0.5 to -8.5 feet, significant improvement has been achieved and the post-surcharge state Su is in general greater than 1,000 psf. For lots 47-48, due to the presence of thick clay layers (17 feet) and the extended depths (to El. -18 to -21 feet), even though strength gain is obvious, there is still significant thickness of soft clays with Su of less 1,000 psf at post-surcharge state.

Accidental Surcharge on Lots 35-48 – Settlement

Soil modeling for theoretical settlement predications has been discussed previously. Based on these soil models, using Terzaghi's one dimensional consolidation theory, under the full surcharge height at El. +35 feet, approximately 19 inches of consolidation settlement was predicated. If projected to 30 years, the magnitude of secondary settlement ranged from 3 to 9 inches based on correlations of primary and secondary compression coefficients presented by different researchers.

Actual surcharge settlement data provided a unique opportunity of understanding discrepancies between theoretical predications and actual site behavior. Settlement data were measured by Plates 289 to 306 from September 2006 to March 2010 a period of about 42 months. The plate locations and the measured settlements are shown in Figure 8.

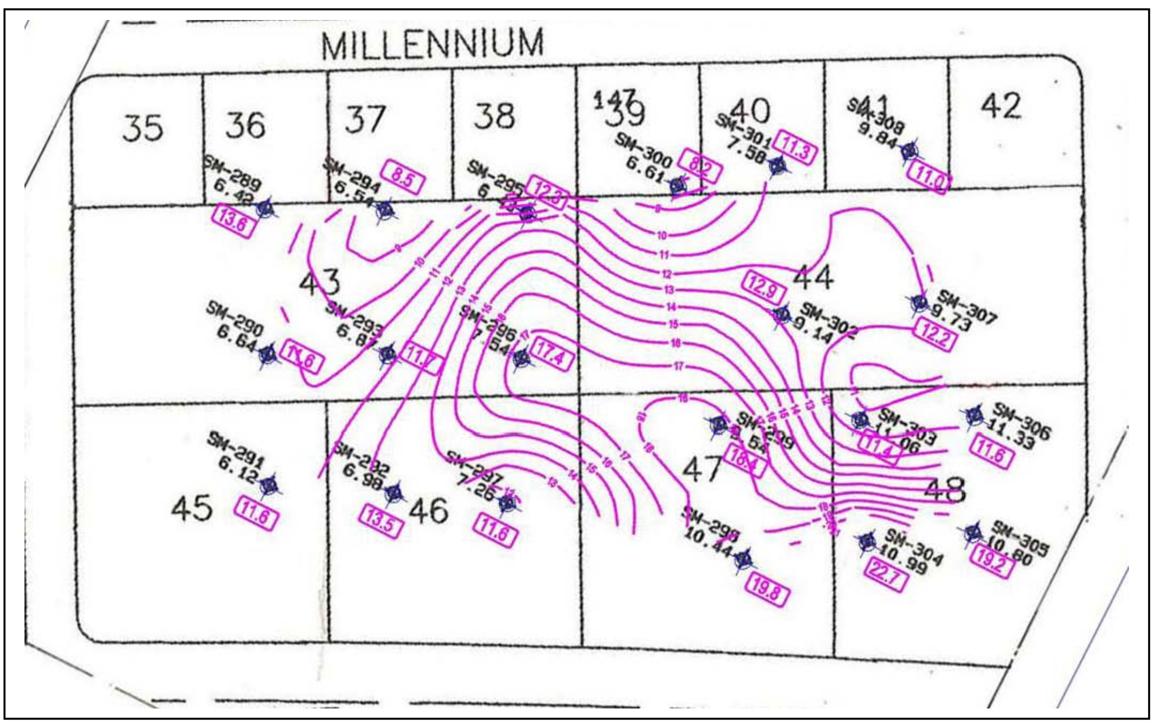


Figure 8: Settlement plate locations and 1-year settlement contours

From Fig. 8, it is observed that the predicated primary settlement agrees reasonably well with the measured 1-year settlement. As discussed in previous sections, the thickness of soft clays with Su of less than 1,000 psf are thicker at lots 47-48 (17 feet) compared with that of lots 35-46 (ranges from 3 to 12 feet). As anticipated, the settlement measurements also exhibit similar trends with the highest settlements being measured in lots 47-48 for 18 to 23 inches; compared with 11 to 14 inches measured in lots 35-46.

To understand the behavior of time rate of consolidation and the initiation of secondary compression, a comparison of measured settlements was made with theoretical calculations. We used settlement data of settlement plate SM-298, located in lot 47, which measured a total settlement of 20.8 inches from 2/13/2006 to 1/14/2010 for a period of 1128 days (37.6 months / 3.12 yrs) at full surcharge El. of 35 feet. A time rate settlement calculation has been made based on B15C549. It should be recognized that theoretical time rate calculations, at the best, can only provide a rough approximation for true settlement behavior in the field for the following reasons:

- Drainage path is very difficult to determine;
- Subsurface soils can varies significantly spatially;
- Coefficient of consolidation (C_V) is a very difficult parameter to measure;
- Three dimensional effects are not modeled;

In our calculations, the average C_V, coefficient of consolidation of 0.1 ft^2/day was assumed based on correlations provided in the Navy Manual (Figure 3-6 in Navy Manual). We assume that half of the thickness of soft clay is the longest drainage path which in general may be reasonable considering the fact that there are some silty layers sandwiched in the clay layer. Figure 9 shows the comparison of theoretical calculation and measured data for lot 47 based on SM-298.

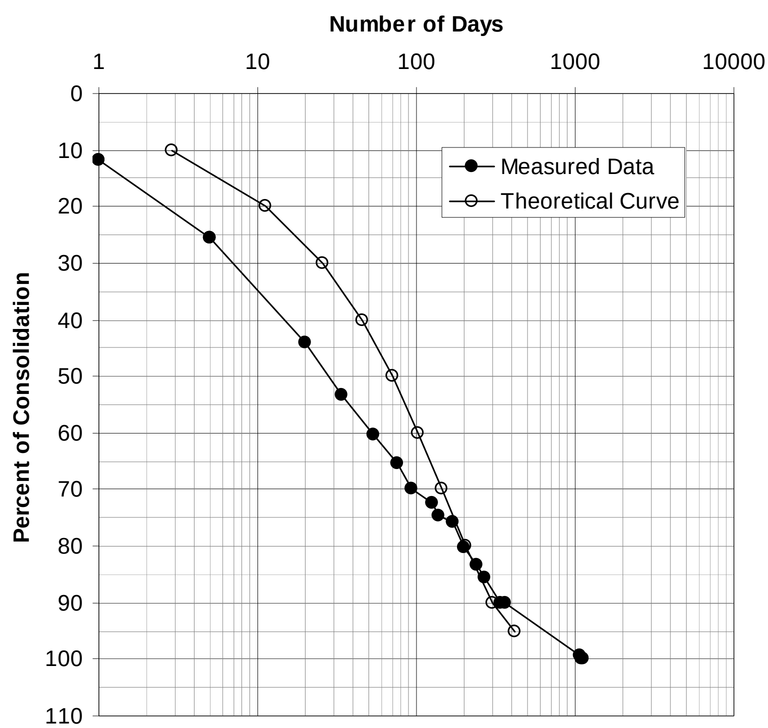


Figure 9: Time rate of consolidation: theoretical calculation and measured.

Even with the above mentioned uncertainties, it appears logical to assume that 90% of the primary settlement was completed within about 1 year, and secondary settlement was initiated beyond that point. However, due to the uncertainties discussed, and the difficulties and uncertainties involved in calculating the secondary compression coefficient, the actual settlement data was analyzed for gaining insight into secondary compression. Figure 10 shows the measured settlement data for a period of 4 years.

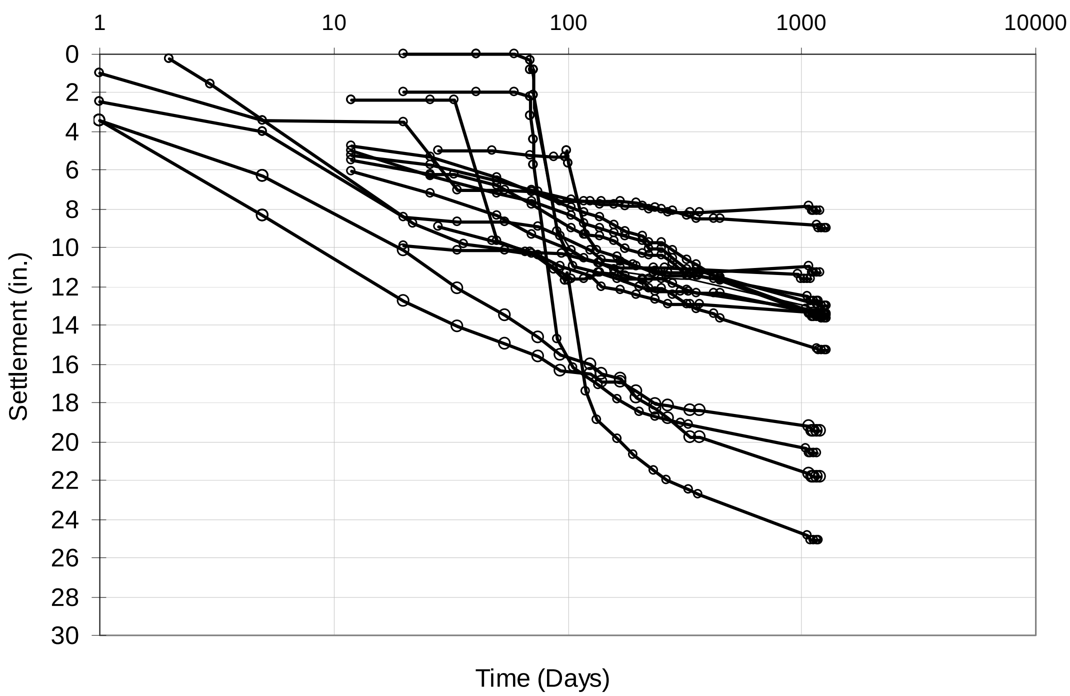


Figure 10: Measured settlement with time.

As shown in Fig. 10, with a few exceptions, most of the settlement plates indicate clear evidence and consistent trend of secondary settlement within the time frame of 1 to 4 years. Based on the slopes between 1 and 4 years, the maximum rate of this secondary settlement is 0.01 inches per month. If projected for 30 years, and assuming primary settlement was completed in one year, the total secondary settlement appears to be about 3.6 inches. Calculated secondary settlement using the two theoretical methods ranges between 2.6 and 6.9 inches. Given the wide range of calculated secondary settlement, it is more appropriate to use the actual settlement data (Figure 10) to define the secondary settlement.

Conclusions

An unintentionally long surcharge over a period of 4 years offered unique opportunity for gaining insight into to the long term behavior of soft organic clays under extended loading. Long term surcharge settlement monitoring data and pre- and post- surcharge investigations offered extensive amounts of data for analyzing and understanding the contributing factors of shear strength gains, including the thickness and depth of soft organic clays, surcharge height and duration, and drainage path for pore water pressure dissipation. As anticipated, site improvement by surcharging was greatly affected by the depth and thickness of the soft clay and the drainage path. At the study site, the gain in undrained shear strength corresponds to approximately 12 percent to 17 percent of applied surcharge pressure. Time rate consolidation can be approximated with reasonable selection of coefficient of time rate consolidation and appropriate drainage path. Secondary compression should always be considered when planning surcharge scheme. At the study site, the amount of secondary settlement could amount to 3.6 inches. Secondary settlement may be mitigated by placing additional surcharge.

Reference:

Mesri, Golamreza, "Primary Compression and Secondary Compression," Soil Behavior and Soft Ground Construction," Geotechnical Special Publication No. 119, Edited by John T. Germaine, Thomas C. Sheahan, and Rober V. Whitman, Proceedings of the Symposium, Cambridge, Ma, October 2001.

Mesri, G., Stark, T. D., Ajouni, M. A., and Chen, C. S., " Secondary Compression of Peat with or without Surcharging," Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123, No. 5, May, 1997, pp 411-421.

(NAVFAC) Naval Facilities Engineering Command, "Soil Mechanics, Design Manual 7.01," 200 Stovall Street, Alexandria, VA 22332-2300, Revalidated 1 September 1986, p.7.1-144.