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Nguyen Minh Hai

*Thu Dau Mot University, Binh Duong, Vietnam*

Bengt H. Fellenius

*Consulting Engineer, Canada*

# ANALYSIS OF PILED-RAFT FOUNDATION FOR CAI MEP CONTAINER PORT, VIETNAM

**Nguyen Minh Hai**
Faculty of Civil Engineering,
Thu Dau Mot Univ. Binh Duong,
Vietnam. haitdmu@gmail.com

**Bengt H. Fellenius**
Consulting Engineer, 2475 Rothesay Ave., Sidney,
British Columbia, Canada, V8L 2B9.
Bengt@Fellenius.net

ABSTRACT

During the last decade, a series of ports are being built along the Thi Vai River in the Mekong delta approximately 80 km southeast of Ho Chi Minh City, Vietnam. The ports are built on reclaimed ground over an about 30 to 40 m thick deposit of soft, normally consolidated, compressible clay deposited on dense to compact sand The deep foundation system typically used for buildings in this region consists of pretensioned spun high strength concrete piles driven to significant toe bearing in dense soils. Because of the anticipated significant costs of this solution, a more economical alternative foundation system was essential, and the alternative of a shaft bearing pile, a precast concrete pile, was proposed for Cai Mep Container Port. To reduce settlements, a soil improvement scheme was imposed, consisting of wick drains installed through the clay to the sand and placing an up to 8 m thick surcharge over the area. After removal of the surcharge, piled-raft foundations were constructed for the Port building, incorporating 400 mm square, precast concrete piles, which were driven to depths of 18 m. Settlement monitoring showed that the area and the piles continued to settle after the removal of the surcharge, indicating that consolidation settlement had not been completed despite the about 18 months long surcharge period. It became clear that the long-term settlements, primarily due to downdrag, would exceed the limit of maximum 400 mm over a 20-year period. In order to remedy the situation, the piles were lengthened to a total length of 44 m to ensure that the neutral plane was located in the sand, where no long-term settlement would occur. The problem and its solution were analyzed by means of the Unified Design Method. The remedial solution added about US$2 million to the project and caused a 12-month delay.

## 1. INTRODUCTION

In 1999, the Vietnamese government proposed a Detailed Master Plan for Port Development along the Thi Vai River in the Mekong Delta approximately 80 km southeast of Ho Chi Minh City, as shown in Figure 1. The highest priority portion is the Cai Mep Container Port, which covers an area of about 800 m by 600 m.

The early work for the foundation design of the buildings was carried out by Japan International Cooperation Agency (JICA). The design addressed the consolidation settlement, the differential settlement, and the negative skin friction affecting the piles over a period of 20 years following the construction. The long term requirement for the site was that post-construction settlement of neither the building nor the general area should exceed 400 mm over a period of 20 years including consolidation of the clay due to pavement and fill for roadways and loading areas placed in the final stages of the construction and effect of secondary compression.

The area is dominated by an about 30 to 40 m thick soft compressible clay layer and, therefore, all structures require deep foundations. The deep foundation system normally used in this region consists of pretensioned, spun cast, high strength concrete piles, usually 500 to 600 mm circular diameter driven to significant toe bearing in the underlying dense soils. Because of the anticipated significant costs of this solution, and the relatively light-weight structures involved, the JICA desired a more economical foundation system and proposed the alternative of supporting the buildings on shaft-bearing piles, which enabled the use of piled raft foundations supported on lightly driven, square 400 mm diameter precast concrete pile made up by 10-m segment spliced in the field by welding. The piles were to be driven after a site improvement scheme involving acceleration of settlement by means of wick drains and surcharging the area and had been completed. This paper focuses on two buildings named Maintenance Shop and Substation. The authors have presented a previous paper addressing issues pertaining to two other and heavier buildings at the site (Fellenius and Nguyen 2013).


*Fig. 1. Satellite Image of the Project Area*

The highest water level expected at the site is Elev. +4.0 m, which requires raising the ground elevation by about 2.0 m to Elev. +5.5 m in order to avoid flooding and to create a suitable foundation surface. Because of the thick very compressible clay and silt layer, the fill placed to raise the land will cause significant settlement, which would continue for a very long time. To shorten that time, vertical drains (wick drains) were installed to 37 m depth across the site. Moreover, a temporary surcharge was added raising the surface to Elev. +8 m through Elev. +10 m, i.e., a surcharge was placed consisting of an additional 2.5 m to 4.5 m of fill height. The settlement of the area was continuously monitored by survey of ground surface benchmarks installed at the start of the placing of the fill. It was expected that if the surcharge was removed, when 80 % to 90 % of the consolidation settlements had developed, the thereafter occurring settlement, i.e., the settlement for the finished facility, would be small and acceptable.

When the surcharge was removed, 18 m total length piles were driven for the building foundations. The settlement monitoring, now also including the monitoring of the pile head elevations, showed that the area and the piles continued to settle after the removal of the surcharge. It soon became clear that the long-term settlements due to downdrag would exceed the prescribed limit of maximum 400 mm for the first 20 years after the completion of the construction of the port.

## 2. SOIL PROFILE

The soil profile at the site consists of an about 30 to 40 m thick layer of clay and silt deposited on sand with trace clay and silt. Details are presented by Fellenius and Nguyen (2013). The groundwater table lies at the original ground surface, Elev.+3.5 m, with some seasonal fluctuation. Pore pressure measurements at depths of 5 m, 10 m, 20 m, and 28 m indicated an upward gradient with a hydrostatic distribution from Elev.+5.0 m, 1.5 m above the ground surface, i.e., artesian condition. CPTU soundings indicated the soil deposit to be soft throughout. The vane shear strength ranged from about 10 through 15 KPa at 2 m depth and increased approximately linearly to about 50 KPa through 80 KPa at 30 m depth, characterizing the clayey silt as soft to a depth of about 20 m and firm below. The correlation coefficient, NKT, between CPTU pore pressure adjusted cone stress and vane shear stress was about 15.

Oedometer tests showed the soil to be very compressible with a Janbu modulus number ranging from about 4 through 6. The tests indicated that the preconsolidation margin was small; the clay was essentially normally consolidated. The reloading modulus number, mr, was approximately ten times larger than the virgin number, m.

## 3. DESIGN AND PILE LOADING TESTS

The site lay-out of Maintenance Shop and Substation is indicated in Figure 2 together with monitoring stations around the buildings. After the piles had been driven, the pile head elevation of several piles was monitored by surveying and these piles are marked out in the figure. The building footprints are 1,680 and 419 $m^2$, respectively.

To prepare for construction of the buildings and the surrounding area, starting in April 2009, an about 1.5 m to 2.0 m thick "reclamation" fill was placed over the original ground level to raise the ground level to Elevation +5.5 m. To offset future settlement, the area was treated with vertical drains (PVD) at a spacing of 1.2 m to about 37 m depth across

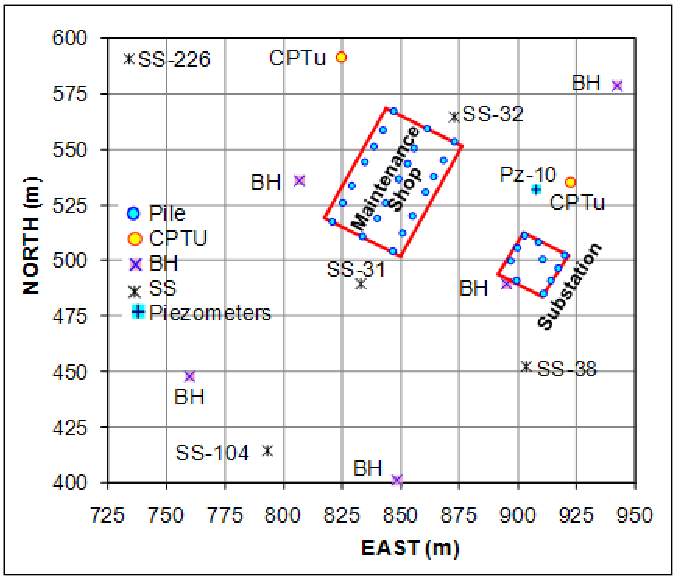


*Fig. 2. Plan view of location of field instrumentation, the two buildings, and the monitored piles*

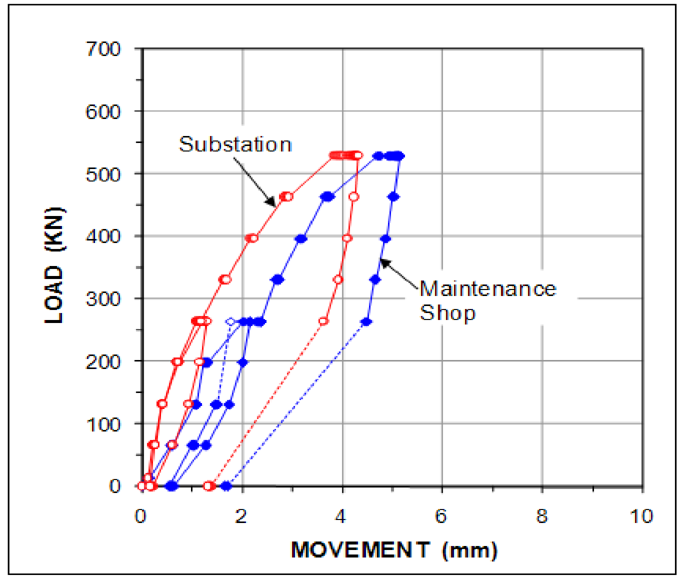


*Fig. 3. Pile-head load-movement curves from static loading tests performed 17 days after driving*

the site (installed in that portion of the site between May 20 and June 20, 2009). Surcharge fill was placed at and around the Maintenance Shop and Substation area starting at the end of September 2009 and continuing through mid-November, 2009, raising the ground level to Elev.+8.3 m. The surcharge was removed down to Elev.+5.5 m on May 20 through June 20, 2011, about 600 days after being placed.

To monitor the effect of the preloading, between June and September, 2009, a large number of settlement plates were installed onto the original ground surface and the development of settlement was then monitored. The monitoring of the settlement plates is still ongoing. No monitoring was undertaken nearby to determine the distribution of settlement with depth at the subject building location.

Piezometers were installed to depths of 5 m, 15 m, and 25 m near the buildings.

The total number of piles supporting the Maintenance Shop and Substation buildings was 256 and 52, respectively. The average pile spacing center-to-center was about 2.7 m and the pile to building footprint ratios were 2.4 % and 2.0 %, respectively. On September 17, 2010, about three months after the surcharge had been removed, two 400 mm diameter piles were driven at each building location to an embedment of 18.4 m and 18.8 m embedment depth, respectively. Seventeen days later, a static loading test was performed on each test pile to twice the intended working load of 265 KN. Figure 3 shows the pile-head load-movement curves of the tests. The tests indicated that the piles showed no sign of having exceeded or even reached capacity. Therefore, all piles for the buildings were chosen to be 18 m long. The production piles were driven during November 16 through December 01, 2010.

## 4. SETTLEMENT MEASUREMENTS

Figure 4 shows the fill stresses and settlements measured at the five plates near the two buildings (benchmarks SS-31, SS-32, SS-38, SS-104, and SS-226) from the start of placing reclamation fill in early January 2009, placing of the surcharge in September through November 2009, removal of surcharge in May-June 2011, and until September 15, 2012; i.e., 0 to ≈300 days, ≈300 to ≈600 days, and 600 to ≈1,300 days. The total average settlement before removal of the surcharge was about 3,000 mm. The average settlement during about 700 days after completion of the pile driving was about 500 mm.

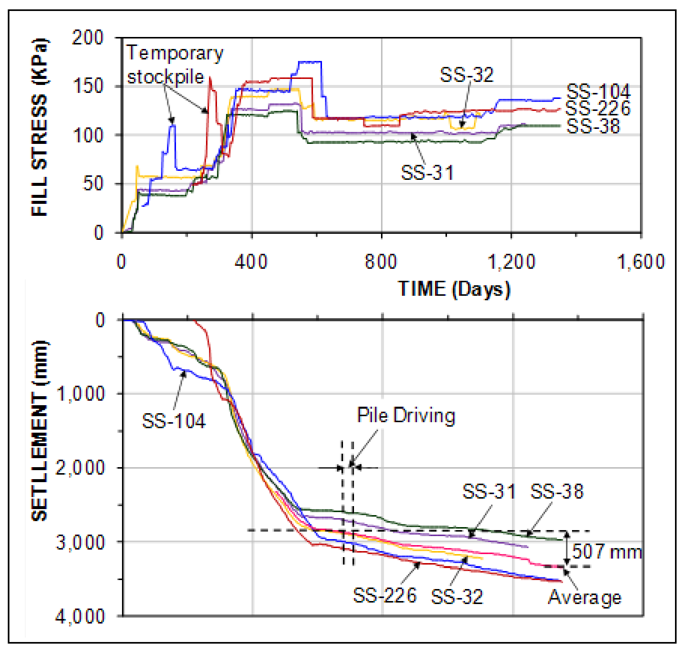


*Fig. 4. Fill stress and settlement vs. days after start*

The continued settling of the area was quite a surprise to the project. After the removal of the surcharge, it was expected that the consolidation would have been completed and settlement would have ceased. The reason for the ongoing settlements has been discussed by Fellenius and Nguyen (2013) and shown to be due to the fact that the wick drains used for the project were not stiff enough to resist the large soil stress at depth and did not did not function below about 20 m depth. That is, below about 20 m depth, the consolidation of the soft compressible soil was incomplete. Indeed, the consolidation continued even after the removal of the surcharge to finished ground elevation, Elev+.5.5 m. Above about 20 m depth, the consolidation was completed. Therefore the measured settlements are those continuing below 20 m depth.

The settlement induced downdrag on the piles, and the piles settled at approximately the same rate as the fill surface. To investigate, upon completion of the pile driving, the pile head elevations were continually surveyed along with the monitoring of the settlement plates outside the buildings. The settlement of the ground surface within the footprint of the Maintenance Shop settlement was monitored in ten points. No similar monitoring was made within the Substation footprint.

Figures 5 and 6 show the average settlement from Day 500 (≈May 1, 2010) through Day 1,370 (September 15, 2012) of settlement plates SS-31, SS-32, and SS-226 near the Maintenance Shop and SS 38 and SS-104, respectively. Each figure also shows the average settlement of all five plates, and includes the average settlements of the monitored piles within the respective building. The pile head settlement has been connected to each SS-plate curve starting at the SS-plate settlement value measured at the end of the pile driving. At about one year after the end to the pile driving (December 1, 2010 through October 28, 2010), it was decided to extend the piles. (Coincidentally, the settlement of SS-32 on December 1, 2009 was the same as the average of all settlement plates).

The measurements show that the 18 m long piles settled along with the surrounding ground; actually slightly more than the ground outside for the first about three months after the end of driving. The difference is due to the fact that the total weight of the piles added stress to the ground, about 7 KPa for the Maintenance Shop and about 5 KPa for the Substation. It is likely that the ground surface inside the building footprints settled about as much and at about the same initial rate as the piles.

The weight of the two buildings on the respective piled raft foundation will impose additional stress over the foundation rafts of 19 KPa and 23 KPa, respectively. No calculation is needed for the actual amount of settlement due to the added values of stress from the building weight to prove that the foundations cannot sustain such additional stress without excessive settlement, unless the piles would be extended.

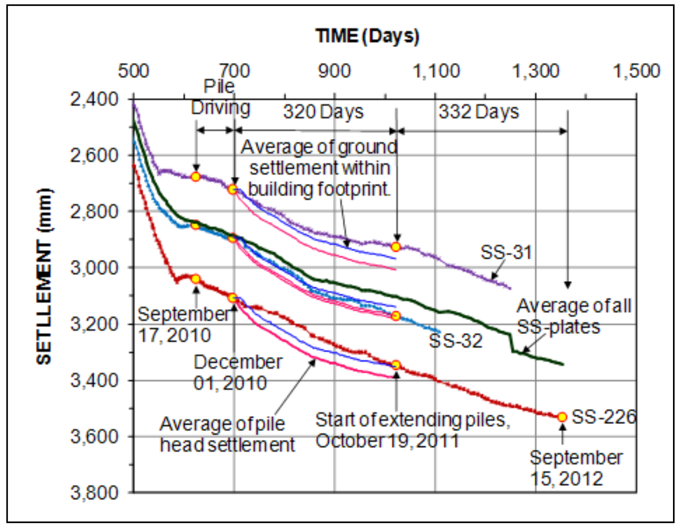


*Fig. 5. Settlement of ground and piles at Maintenance Shop*

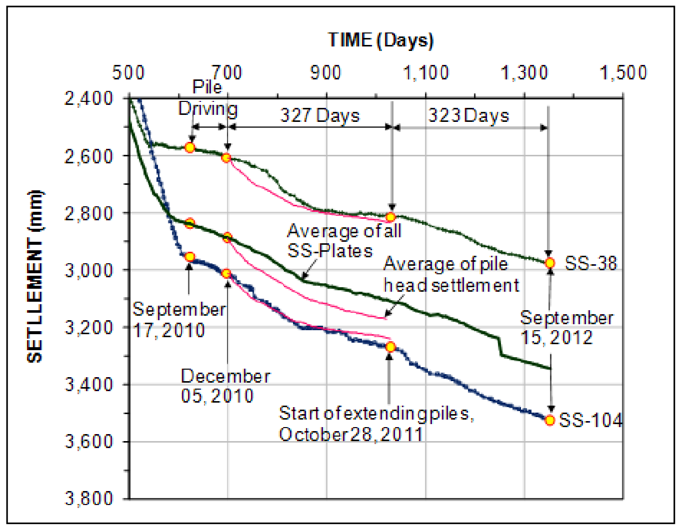


*Fig. 6. Settlement of ground and piles at Substation*

Figure 7 shows a simple hyperbolic extrapolation of the settlement measured after the removal of the surcharge, which suggests that the twenty--year settlement would be more than twice the maximum allowed value of 400 mm. For settlement analysis and discussion of the consolidation at the site, see Fellenius and Nguyen (2013).

5. FOUNDATION ANALYSIS AND REMEDIAL SOLUTION

Figure 8 shows the typical capacities, the load and resistance distributions, and the neutral plane location calculated by effective stress analysis using the UniPile program (Goudreault and Fellenius 2012) for the 18 m long piles. The calculations are based on back-calculation of the results of the static loading tests, using effective stress coefficient (beta) of 0.2 and a unit toe resistance of 470 KPa. The neutral plane location calculated for the 265 KN dead load is at about 8 m

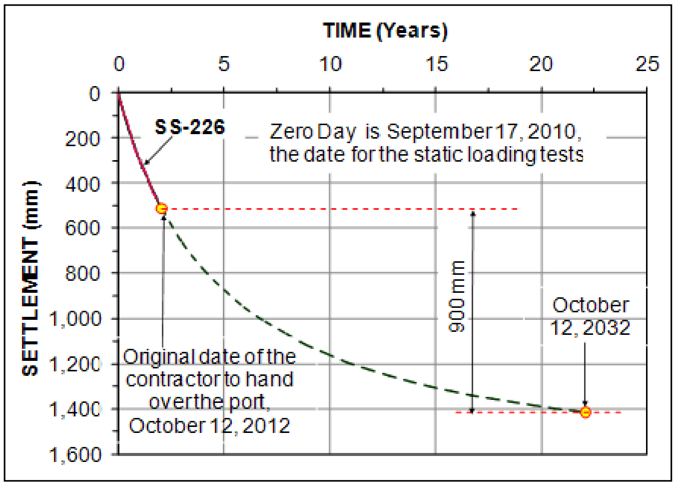


*Fig. 7. Ground settlement vs. time at SS-226*

depth. The drag load is of no concern for the piles. However, the downdrag (settlement) due to the ongoing settlements for the piles will be significant. Indeed, were the neutral plane even as low as at the pile toe, the downdrag would still be excessive for the foundation.

It was realized that the neutral plane must be brought down into non-settling soil, that is, into or just at the surface of the sand layer found at 35 to 40 m depth. The piles were therefore extended to 44 m total length. Figure 9 shows the typical calculated load and resistance distributions, and the neutral plane location for the new length. The calculations applied the same beta-coefficients for the clay as for the shorter pile. The coefficient in the sand was input as 0.4 and the assumed mobilized unit toe resistance was 10 MPa. The calculation showed the neutral plane to lie at the surface of the sand layer.

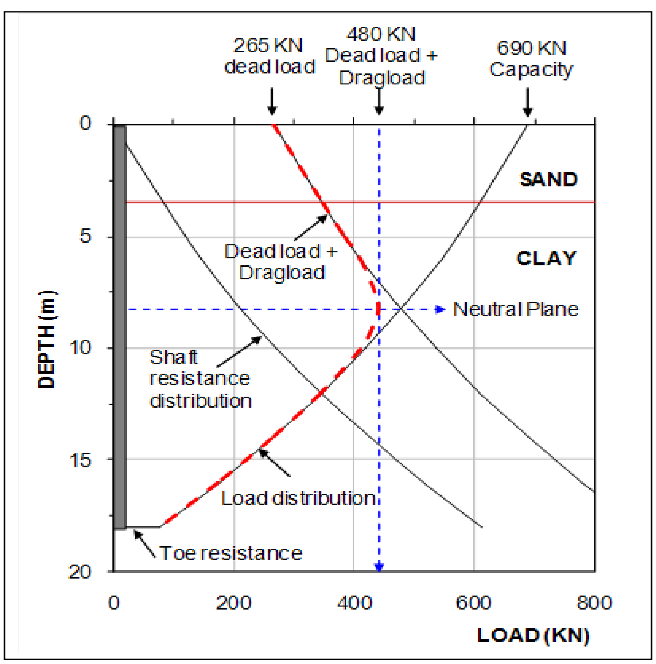


*Fig. 8. Distribution of load and resistance of 18 m pile*

A conservative calculation of the total load in the pile (dead load plus drag load) indicated it to be about 2,500 KN, which was considered acceptable for the pile structural strength.

Figure 10 shows a photograph of the Maintenance Shop during ongoing pile lengthening work. The average pile depth is 44 m. The termination of the driving was governed by a dynamic formula which resulted in about one metre variation of the pile depths.

The lengthening of the piles for the two buildings was completed on December 27, 2011. Figure 11 shows the building settlements from end of lengthening through September 14, 2012. The initial settlement is due to the 'elastic' shortening of the pile from the weight of the building being constructed during the first month. Thereafter, the building settlement has been small. However, it still amounts to about 3 mm in 5 months, i.e., 140 mm in 20 years, although the actual settlement would likely be smaller than that suggested by such linear extrapolation.

As expressed by Fellenius and Nguyen (2012), the general area of the port grounds will require frequent maintenance of the surface elevation to ensure, in particular, that the grounds will not settle below flood level. This will necessitate adding fill, which will trigger renewed consolidation. Because the drains function in the upper 20 m zone, the main portion of the consolidation settlement triggered by the new fill will occur quickly and the time intervals between placing new fill will be correspondingly frequent. However, as the neutral plane is safely located below the settling clay, the area settlement will not impose significant downdrag for the piled foundations.

The remedial solution added about US$2 million to the project and caused a 12-month delay to the project.

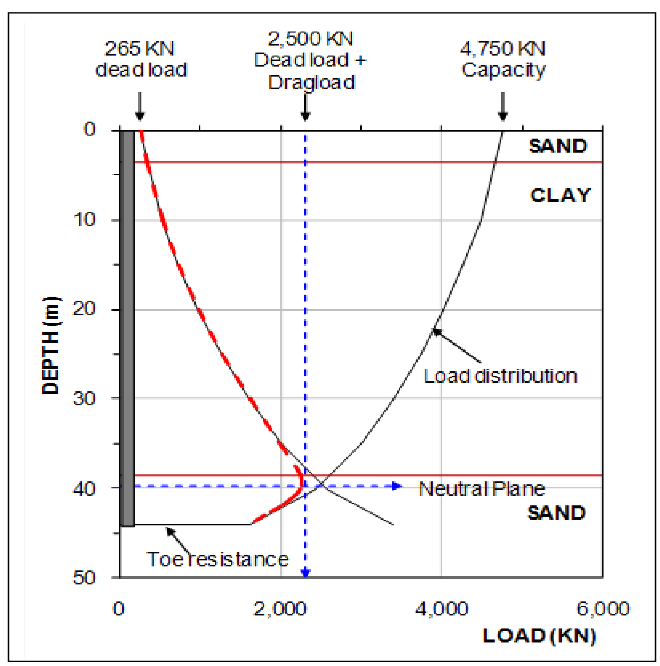


*Fig. 9. Distribution of load and resistance of 44 m pile*

*Fig. 10. View on Feb. 10, 2012, of the Maintenance Shop area with about half the piles lengthened (Authors' photo)*

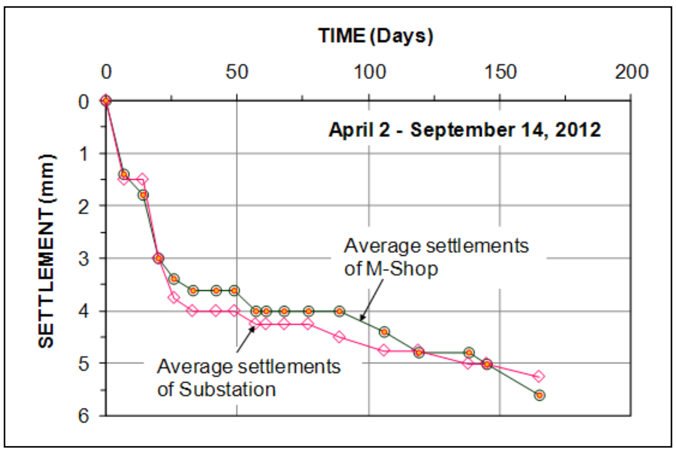


*Fig. 11. Settlement of the two buildings after piles had been lengthened*

## 6. SUMMARY AND CONCLUSION

The observations and analyses have indicated the following.

The inability of the wick drains to function at depths deeper than 20 m resulted in incomplete consolidation of the clay below this depth.

The settlement monitoring showed that the settlements continued after removal of the surcharge and extrapolation of the records showed the long-term settlement will be more than twice the value indicated as acceptable for the building already before considering the effect of the building weight.

The piles, having no load applied, settled at the same rate as the ground because the settlement occurred below the 18 m depth of the piles and the piles were subjected to downdrag.

The remedial solution accepted was to extend the piles so that the neutral plane would be below the clay and, therefore, no further downdrag would occur.

The observations during the first five months after the piles were extended showed that the settlement of buildings was small.

The general area of the port grounds will require frequent maintenance of the surface elevation, which will involve adding fill, thus triggering new consolidation.

## ACKNOWLEDGEMENTS

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