

First application of electro-osmosis to improve friction pile capacity—three decades later

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It is the intention of the Editorial Panel occasionally to publish Papers which have been published elsewhere, are of particular interest and would not easily be accessible to the readership of this Journal. This short Paper was presented at the 13th International Conference on Soil Mechanics and Foundation Engineering in New Delhi early in 1994 and it is of interest because it provides a long-term case study of pile load bearing behaviour, following the use of electro-osmosis to improve the friction capacity of steel H-piles in soft varved clay and silt soils.

- **The problem of founding the Big Pic River Bridge on some 100 m of soft varved clay and loose silt deposits is described. Due to the presence of excess hydrostatic head at depth, the capacity of long friction piles was markedly less than that of short piles; consequently, it was decided to found the structure on short, steel H-section friction piles within the upper clay and to apply electro-osmotic treatment. The overall effect of the electro-osmosis was markedly to increase the pile capacity. It is believed that this is the first example of electro-osmosis being used to improve friction pile capacity. Further tests have since been carried out over the past 33 years to assess the permanence of the increase in pile capacity. No reduction in the load bearing capacity of the piles has been measured over this period and recorded settlement of the bridge foundations has been minimal.**

Introduction

This Paper describes the use of electro-osmosis to increase the bearing capacity of friction piles for the substructure support at the Big Pic River Bridge, which is a three-span, through truss steel cantilever structure, over 180 m in length. It is one of many along the route of the Trans-Canada Highway which, in part, skirts the north shore of Lake Superior. Valleys in this area, of irregular volcanic Precambrian rock, are infilled by considerable thicknesses of stratified glacial lake silts and clays. Electro-osmosis was used when the original foundation design, which called for friction piles driven into the silts at depth, proved to be inadequate.

2. Load tests carried out over a period of 33 years since the original treatment in 1959 have

demonstrated that pile capacities have not diminished with time.

Site geology

3. The subsoil stratigraphy at the site is illustrated in Fig. 1. Bedrock surface was not determined. The upper several metres consist of a compact, fluvial silty sand. This is underlain by about 18 m of medium to stiff, varved silty clay. The varves are composed of dark grey, brittle clay laminae, approximately 25 mm thick, and light grey, clayey silt laminae, typically 12 mm in thickness. The particle size distribution, determined from tests on individual laminae, is shown in Fig. 2. The variations in Atterberg Limits, water content and undrained triaxial and in-situ vane shear strength with depth, are shown in Fig. 3.

4. The varved clay stratum grades into a grey, stratified coarse silt which becomes a silty fine sand with increasing depth. Between depths of 20 m and 50 m, the standard penetration resistance, or N values, ranged from 20–10 blows per 300 mm, gradually decreasing with depth. Artesian conditions were observed on first encountering the silt stratum at 50 m depth. This condition became more pronounced with depth, as reflected in the decrease in N values. The maximum artesian head rose to 6 m above existing ground level at a depth of 80 m. At this depth and below, the N values were sensibly zero due to piping in boreholes.

Pile load tests

5. Because of the low strength, high compressibility and excessive depth of the deposits, a friction pile foundation was chosen in 1959. Steel H-section piles, 300 × 300 mm, 79 kg/m, varying in embedded length from 16.5 to 50.5 m, were driven using a 2 t drop hammer falling 2.5 m. The driving resistance increased linearly



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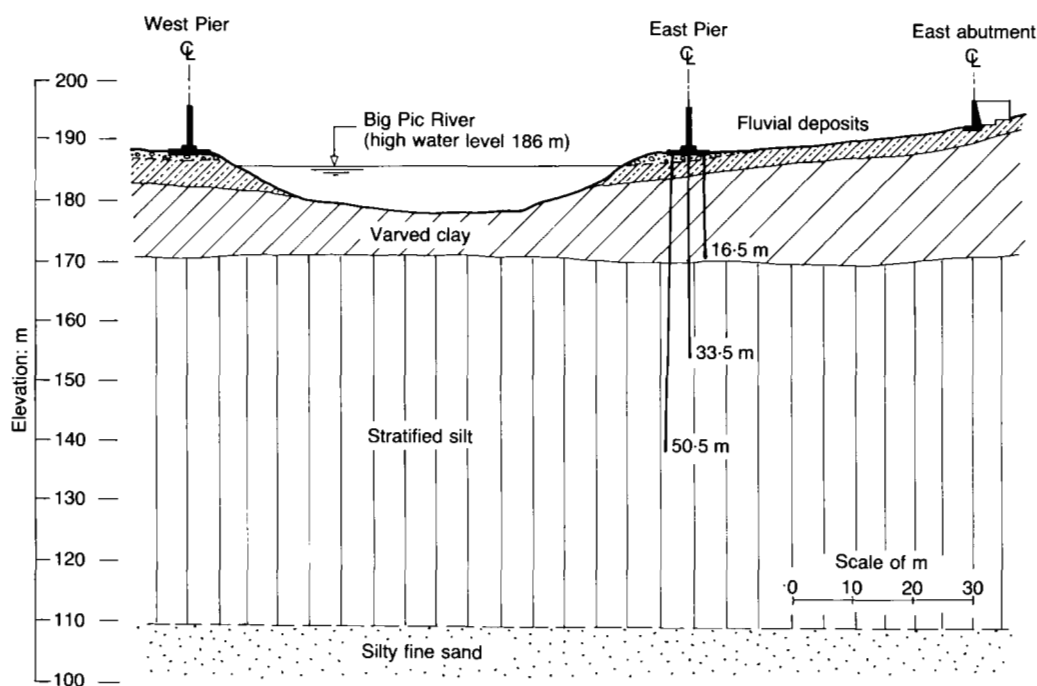


Fig. 1. Subsoil profile at Big Pic River, Marathon, Ontario

with depth to a maximum resistance of about 20 blows for 300 mm penetration at a depth of 50.5 m.

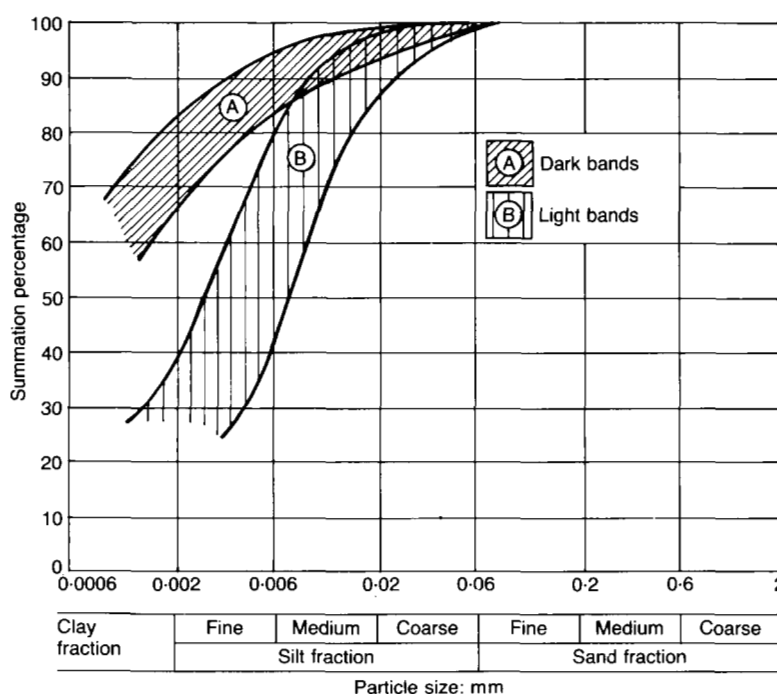
6. The planned design load was to be 350 kN, but load tests on initial piles driven at the site indicated pile capacities of about half this amount. Typical results of static load tests on piles of varying lengths are summarized in Fig. 4. These tests show that static pile capacity actually decreased with an increase in embedded length, due to artesian effects at depth. Piles tested up to 400 days after driving showed no significant increase in capacity above that measured 5 days after driving.

Electro-osmotic treatment

7. In order to avoid a radical change in the design of the bridge at this late stage, it was decided to attempt to increase the frictional resistance of the piles by applying electro-osmosis. A preliminary field test was carried out utilizing two 16.5 m long test piles as electrodes. Under a potential of 115 volts applied by electric arc welding equipment on site, the bearing capacity of the anodic pile, which prior to treatment had carried an ultimate load of barely 260 kN, showed an increase to approximately 500 kN after three hours of treatment. Subsequent laboratory tests by Dr L. Casagrande at Harvard University indicated that with longer duration of treatment even better results could be anticipated. On the basis of these favourable results it was decided to use 16.5 m long piles which would not penetrate into the silt stratum beneath the varved clay and a design load of 135 kN per pile.

8. In Fig. 5, the installation for the West Pier is shown including the arrangement of the cathodes relative to the H-piles, utilized as anodes. The average distance between the electrodes was about 7 m. The layout for the electrical treatment at the East Pier was similar to that at the West Pier. In order to prevent clogging of the cathodic pipes with calcium carbonate, a combination of steel pipes and plastic pipes was used and small holes were drilled

Fig. 2. Grain size distribution for varved clay



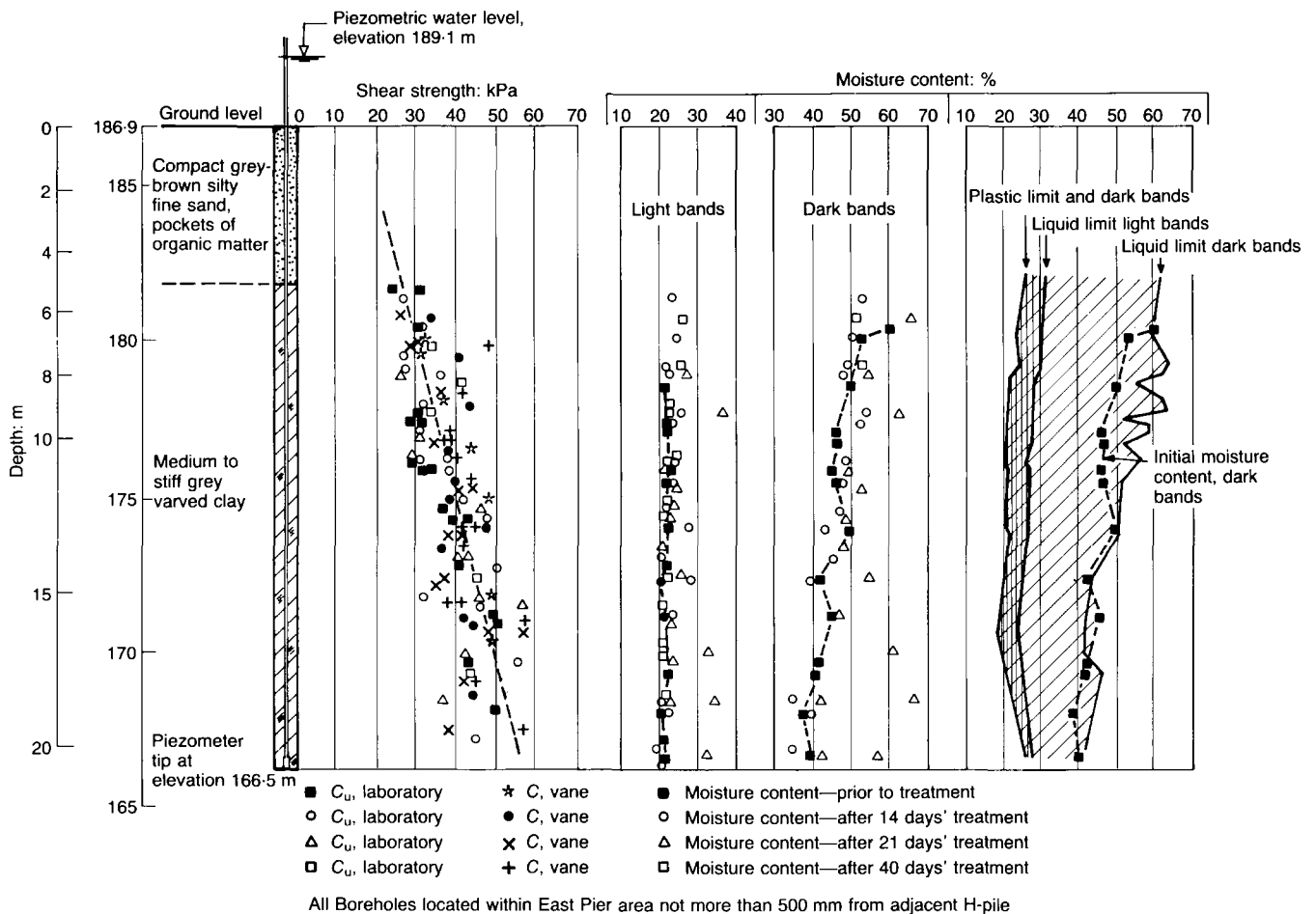


Fig. 3. Geotechnical properties of varved clay

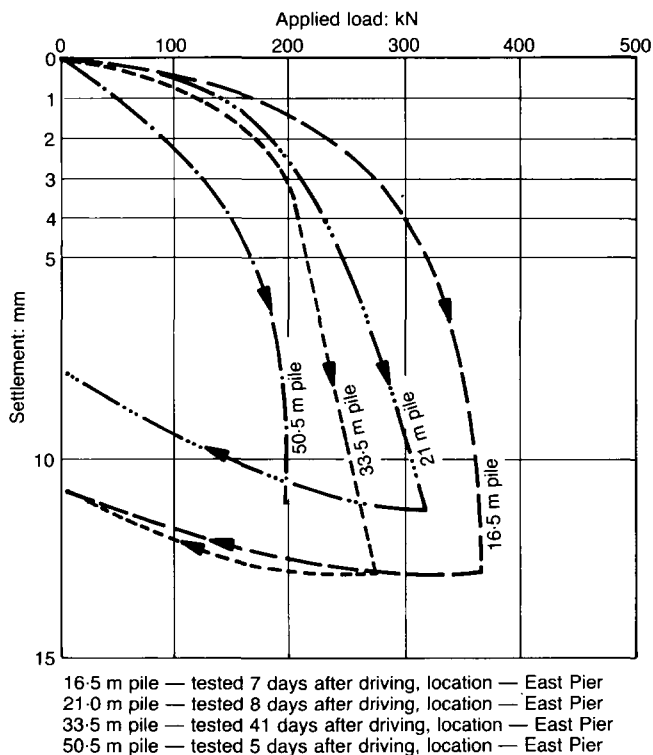


Fig. 4. Typical results of initial static load tests

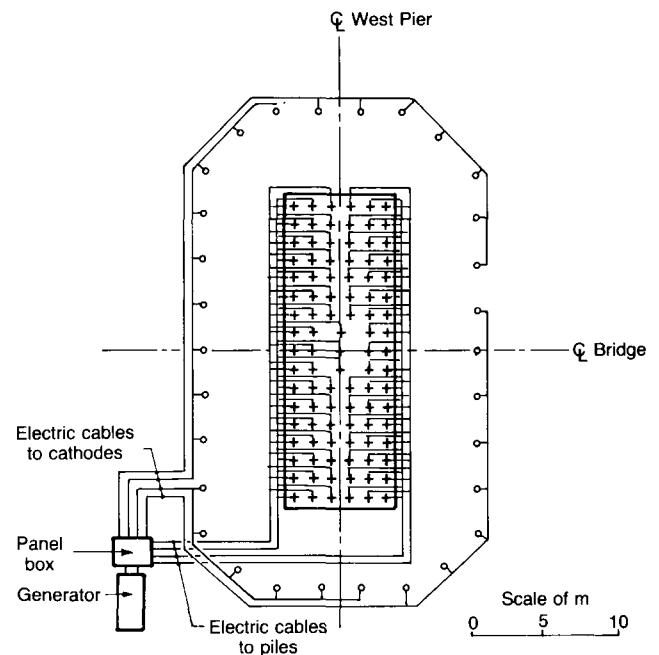


Fig. 5. Electrical layout at West Pier

into the plastic pipe to allow the water (carried by electro-osmosis toward the cathode) to penetrate the plastic pipe and to discharge on the surface. Three diesel generators with an output of 70–120 volts and 1000–600 amps per unit were used. The average current consumption per H-pile for a potential of 100 volts amounted to 15 amps. (Further details of the site and of the pile treatment are given in Soderman and Milligan, 1961,¹ and in Casagrande *et al.*, 1960.²)

Control tests (1959) and subsequently (1960–92)

9. Several H-piles in the foundations of each of the piers were boxed out in order to permit pile load tests to be carried out during and after

electrical treatment. Thus, the progress of increase in bearing capacity with the duration of treatment could be monitored. The results for test pile E-16 in the East Pier are plotted in Fig. 6 and demonstrated a remarkable increase in ultimate bearing capacity from less than 300 kN to over 600 kN, over a period of treatment in 1959 lasting five weeks.

10. Subsequent pile load tests on adjacent pile G-5, also in the East Pier and of the same length, carried out in the period 1960–92, are shown in Fig. 7. It may be seen that there has been no reduction in capacity with time.

11. Load test results in 1959 for test pile E-2 in the West Pier are shown in Fig. 8. Load tests for the period 1961–92 are shown in Fig. 9. Even though pile load capacities are, in this

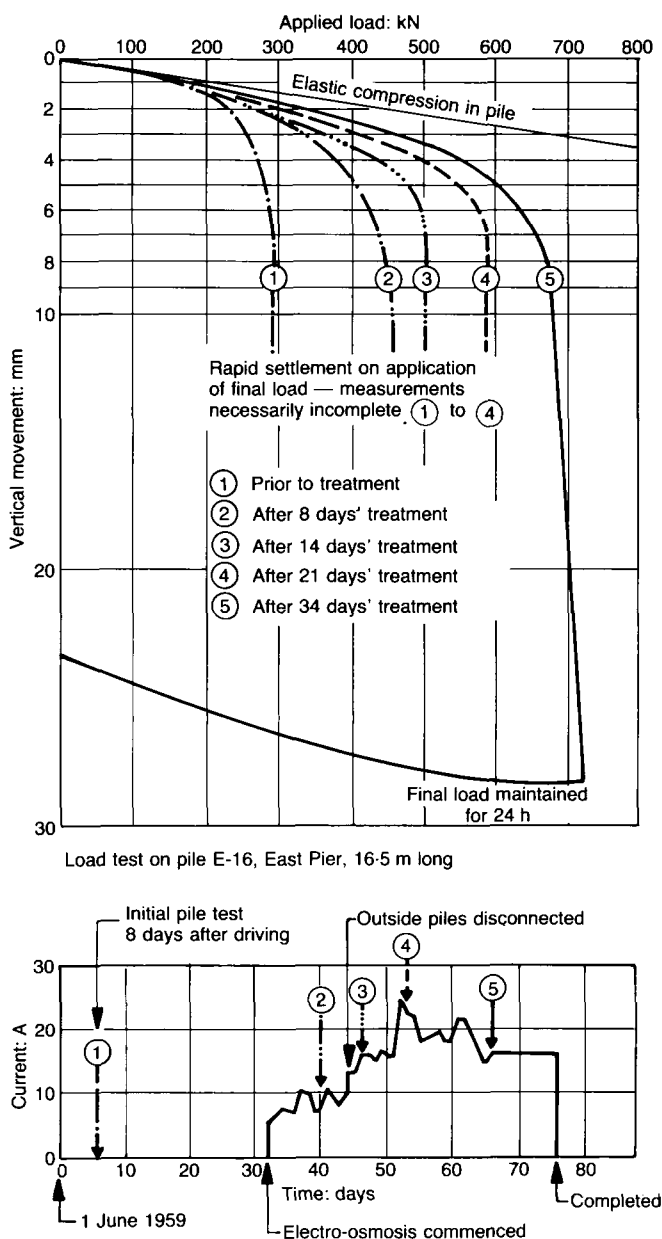


Fig. 6. Pile load tests (1959) — East Pier

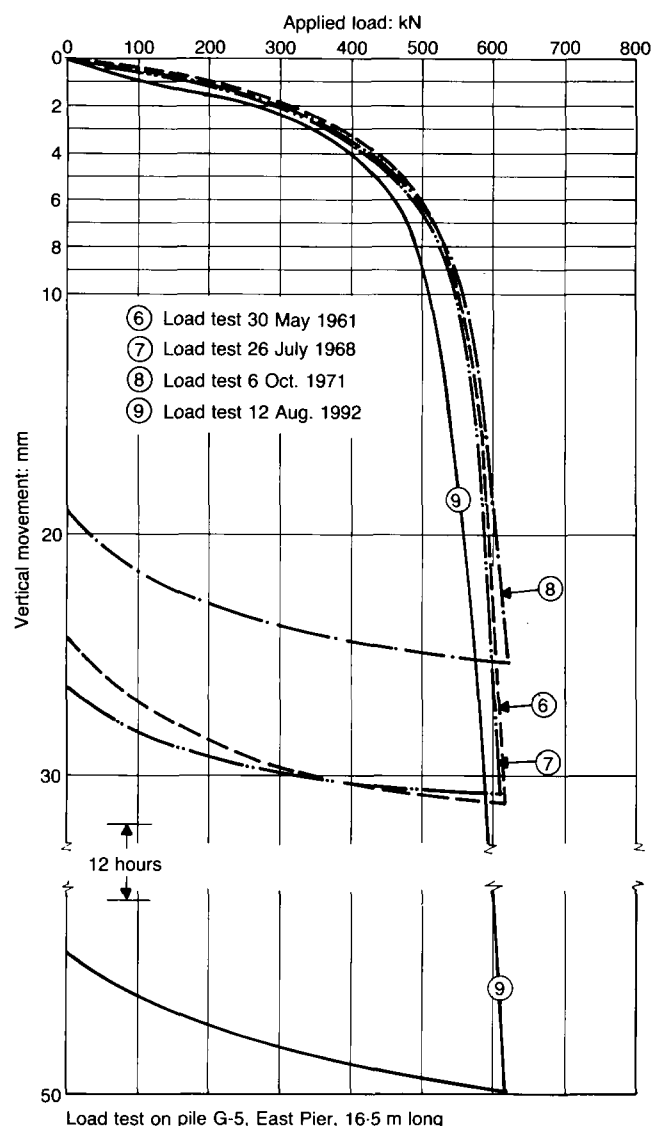


Fig. 7. Pile load tests (1961–1992) — East Pier

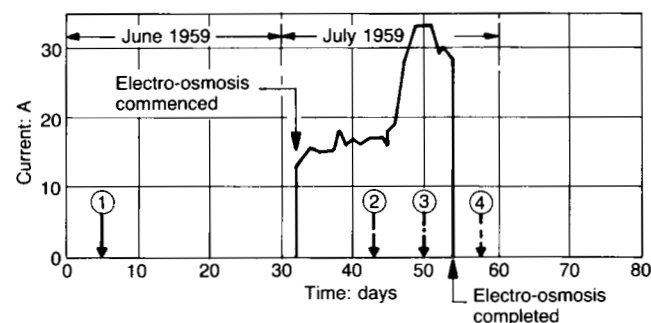
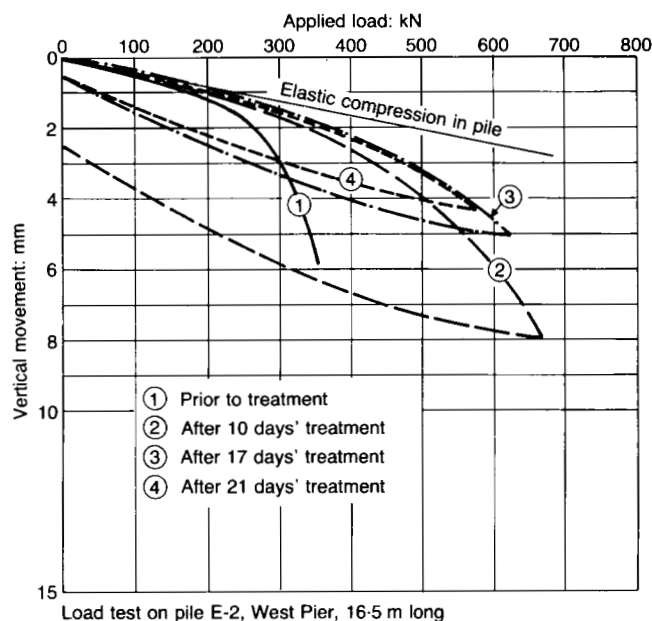


Fig. 8. Pile load tests (1959)—West Pier

case, slightly higher, it can be noted that again there is no reduction in pile capacity with time.

Settlement

12. Recorded settlements of the pier pile caps during treatment (1959) were generally less than 40 mm. Bridge foundation settlements over the past 30 year period have been of the same order and well within acceptable limits for the structure.

Conclusions

13. Electro-osmosis was originally developed as a means of dewatering fine-grained soils (Casagrande, 1952).³ It has also been used to strengthen soft sensitive clays (Bjerrum *et al.*, 1967;⁴ Lo *et al.*, 1991⁵); however, it is believed that this is the first example of it being used to increase friction pile capacity. The significance of these data is extremely important. The fact that load tests have been carried out over a period of some 30 years following treatment and that they have demonstrated the undiminished integrity of the

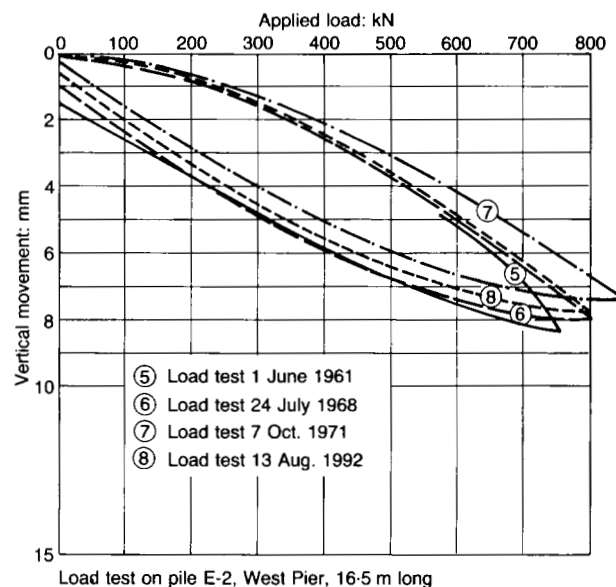


Fig. 9. Pile load tests (1961–1992)—West Pier

foundation is remarkable. Early speculation concerning the long-term effectiveness of electro-osmotic treatment at this site has been answered and the permanence of the process established.

Acknowledgements

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References

1. SODERMAN L. G. and MILLIGAN V. Capacity of friction piles in varved clay increased by electro-osmosis. *Proc. 5th Int. Conf. on Soil Mechanics and Foundation Engineering, Paris, 1961*. Vol. 2, 143–148.
2. CASAGRANDE L. *et al.* Increase in bearing capacity of friction piles by electro-osmosis. Paper presented at the American Society of Civil Engineers Convention, Boston, Mass., 11 Oct. 1960.
3. CASAGRANDE L. Electro-osmosis stabilization of soils. *J. Boston Soc. Civ. Engrs*, 1952, **39**, No. 1, 51–83.
4. BJERRUM L. *et al.* Application of electro-osmosis to a foundation problem in a Norwegian quick clay. *Géotechnique*, 1967, **17**, 214–235.
5. LO K. Y. *et al.* Electro-osmotic strengthening of soft sensitive clay. *Canadian Geotech. J.*, 1991, **28**, 62–73.