Field measurements of the behaviour of lightly-loaded piles in swelling clay

B Sh. Hazzan
Hazzan Foundation Engineering Ltd, Akko, Israel
R W Sarsby
Anglia Ruskin University, Chelmsford, UK

ABSTRACT
A full-scale test site has been established in northern Israel to study the behaviour of lightly-loaded piles installed in a swelling soil. Sixteen unloaded cast-in-situ piles, with uncoated and coated surfaces, were installed in an expansive clay soil. The piles were constructed to different depths ranging between 2.0m and 7.0m and their vertical movements were monitored over a period of 27 months. Another nine unloaded cast-in-situ bored piles, both coated and uncoated, were installed for carrying out pullout tests. Monitoring of the vertical displacement of the piles demonstrated a clear relation between rainfall and movement. Observations and full-scale static pull out tests indicate that separating the piles from the surrounding clay in the active swelling/shrinkage zone, using a twin-walled plastic sleeve, reduced the heave forces significantly.

RESUME
Un chantier expérimental a été établi au nord de l'Israël afin d'étudier le comportement des fondations profondes construites dans une terre qui se gonfle. Seize pieux, qui ne portaient aucune charge, étaient installés dans une couche de l’argile très expansive. Les surfaces de plusieurs de ces pieux étaient couvertes par une couche du bitume ou de la graisse. Les pieux étaient entre 2 et 7m de longueur et leurs déplacements verticaux étaient enregistrés pendant 27 mois. Les résultats montraient une relation très claire entre la précipitation et le déplacement vertical. Les observations des pieux et les essais du chargement soulevant indiquent que les couches du bitume ou de la graisse ont beaucoup réduites des forces soulevantes créés par la terre expansive.

1. INTRODUCTION

In most parts of the world soils undergo seasonal wetting and drying periods and this results in cyclic swelling and shrinkage of the soil. This volume change behaviour is particularly marked for swelling soils and causes problems with foundations, pavements, roads and other engineering structures. Climate change causes cracks and damage in buildings due to movement of the foundations which are caused, generally, by the heave forces acting on the foundations. The problem will be worst for lightly-loaded piles below low-rise buildings. The magnitude of the volume changes and associated heave forces varies according to soil type, annual climate, the characteristics of the dry season, the seasonal temperature variation and other factors such as organic matter content, soluble salts and clay minerals.

With lightly loaded piles founded in swelling clay subsoil anchoring of the piles deep in the ground is needed because the applied vertical load is smaller than the heave force. If it is impossible to drill into underlying rock, the length and diameter of the pile may be too small to provide sufficient resistance to the applied vertical load from the building. In such a case the usual solution is to increase the pile diameter, but by this way the heave forces on the pile, due to the climate change, will increase because of the increase in the contact area between the swelling soil and the pile shaft. On the other hand, if it is possible to drill into underlying rock, a pile might fail in tension due to upward heave forces. A potential solution to the foregoing problem is to provide a ‘slip layer’ between the pile and the surrounding soil in the zone of soil expansion. In the last four decades significant effort has been devoted to designing piles in swelling soils which could accommodate the effects of climate change, but to date only scant effort has been made to the eliminate the heave force acting on the upper part of lightly-loaded piles (Hazzan, 2004).

2. THE TEST SITE

The site is located in northern Israel where there are significant soil deposits with clay contents in excess of 35% and with 40 to 80% of the clay mineral, i.e.montmorillonite, being especially prone to high volume change due to moisture change. In Israel the dry season lasts for 6 months and the annual temperature variation is very large, i.e. from -4^0 C in Winter to 46^0 C in Summer. Total annual precipitation varies from about 450 to 1000 mm in the North of Israel at Karmiel (where the test site is located) to as little as 20 mm in the South, at Eilat. For the test site the total measured annual rainfall in the three consecutive winter seasons covering the pile monitoring period was: 437mm, 965mm and 507mm. The site is flat and covered with short, native grass.

The soil profile was determined using a rotary drilling rig to carry out four exploratory borings with augers of 100mm diameter. The soil characteristics were defined from in-situ field tests (Standard Penetration Test, Vane Shear, Dynamic Penetration Test) and laboratory tests on seven undisturbed soil samples. The soil profile generally consists of stiff fat clay to a maximum depth of 7.2m. Within the clay deposits three separate soil strata are clearly identifiable:

- The top 4m of ground consists of brown clay which is designated as CH in the Unified Soil Classification system – Layer A.
- The next 1m depth consists of a brown clay containing fine limestone particles (1 to 3mm in diameter) – Layer B.
- The clay in the bottom stratum contains coarse limestone particles between 3 and 5mm in diameter – Layer C.

The properties of the clay are summarised in Table 1. The values of Liquid Limit and Plasticity Index mean that the clay is located above the 'A-line' in the Plasticity Chart. The Shrinkage Limit was between 11 and 13%.

Table 1 Soil properties at the test site

Layer	Moisture Content (%)	Specific Gravity	LL (%)	PL (%)	Freeswell (%)
A	19-34	2.73	64 – 69	23 – 26	118
B	27-32	2.74	60	27	85
C	26-30	2.75	56	29	72

3. TEST PILES

All piles were conventional reinforced concrete piles. A rotary drilling machine was used to install 16 vertical piles at the end of Summer. This installation date was selected as it was anticipated that wetting of the soils, which dried during the Summer period, would produce maximum uplift forces on the test shafts. These 16 piles had diameters of 0.4 and 0.5m and were embedded to depths ranging between 2m and 7m.

Nine vertical piles, for pull-out testing only, were installed in Autumn and vertical movements of these piles were not measured. These latter piles had diameters of 0.5m, 0.6m and 0.7m and all were 2m long. To minimise adhesion and friction between a pile and the surrounding soil in the zone where swelling is most severe, twin-walled plastic sleeves (2m and 3m long) were installed around the top part of approximately half of the piles. The inner sleeve was in direct contact with the concrete of the pile and the outer sleeve was in contact with the soil. The space between the sleeves could be dry or could contain viscous lubricating grease.

4. RESULTS

4.1. Ground movements

Settlement tell-tales were installed at various depths within the soil and on its surface to monitor ground movements and the results are shown in Figure 1. During the monitoring period the ground surface had a maximum heave of about 58mm and a maximum settlement of 12mm, i.e. a vertical displacement amplitude of about 70mm. There is a clear correlation between rainfall and ground movement, apart from when the site was flooded (April and August 1997) due to a burst water main. The flood water rapidly penetrated the ground, through cracks created by drying, and heave occurred at a time when the trend was for settlement.

By calculating the vertical strain distribution in the soil (using the data from the tell-tales at different depths) the depth of the desiccated/expansive zone was estimated to range between 2.0m and 2.50m, i.e. approximately the depth range of the pile sleeves.

4.2 Pile movements

The vertical movement of the tops of two typical short piles (numbers 13 and 14) are shown in Figure 2. This Figure clearly demonstrates the connection between rainfall and observed vertical displacement – except when the site was flooded. As described in the previous section the flood water rapidly penetrated the ground through cracks and initiated swelling at depth rather than it progressing from the ground surface downwards. This had a significant effect on the displacement behaviour of short piles and caused the anomalous movements seen in Figure 2. There is a clear difference between the amount of heave that each pile h s undergone since installation. This is believed to be due to the fact that the concrete of one pile (number 13) was in direct with the surrounding ground whereas with pile 14 the concrete was enclosed within a lubricated sleeve.

4.3 Uplift load capacity

Uplift loads were applied to the tops of selected piles by jacking up a load frame (which was attached to a pile) against vertical piles which provided a reaction force. The load was applied in small increments using a hydraulic jack and after each increase the load was kept constant for 15 minutes whilst vertical movement was monitored. After pull-out of a pile had been achieved the load was reduced, in steps, down to zero. The short, sleeved piles were then subjected to a downward-acting load (applied in increments) until there was sliding between the pile and the sleeve in contact with the ground.

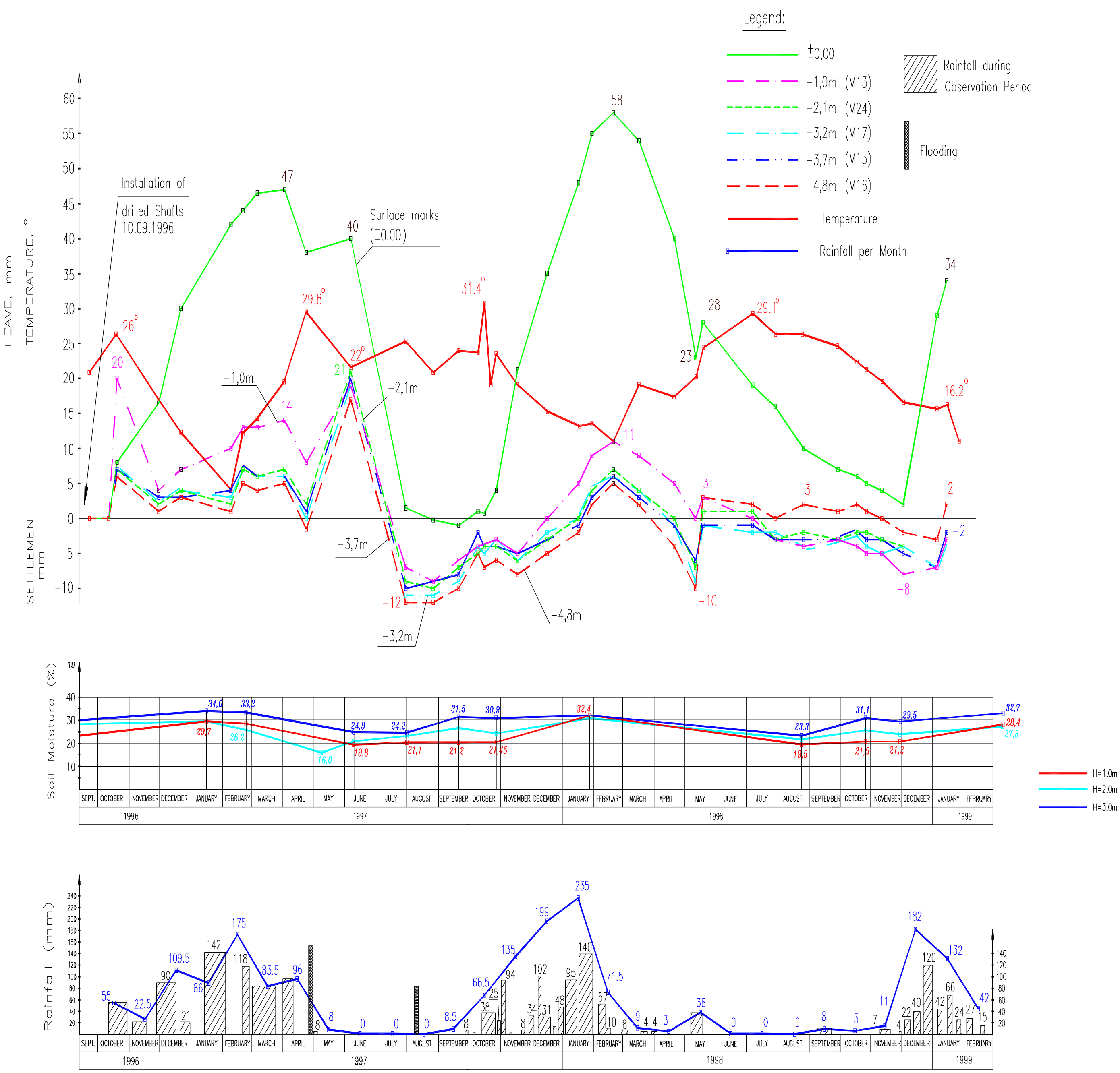

Figure 1. Vertical movements in clay layers and at the ground surface

The load-displacement measurements obtained from the field load tests were interpreted using several methods (Kulhawy and O'Rourke, 1980) to determine the uplift capacity of each pile. Most of the methods defined similar 'failure' loads, i.e. within plus-or-minus 10% of the mean value. To initiate sliding between a pile and a sleeve only required the application of a shear stress of about 10 kN/m^2 – this equated to a reduction of soil-pile adhesion by up to approximately 80%. For sleeved piles a displacement of less than 0.1% of the pile diameter was all that was needed to mobilise the full load capacity of a pile. On the other hand, the conventional piles required a displacement of between 0.7% and 0.8% of the shaft diameter to mobilise the 'failure' load.

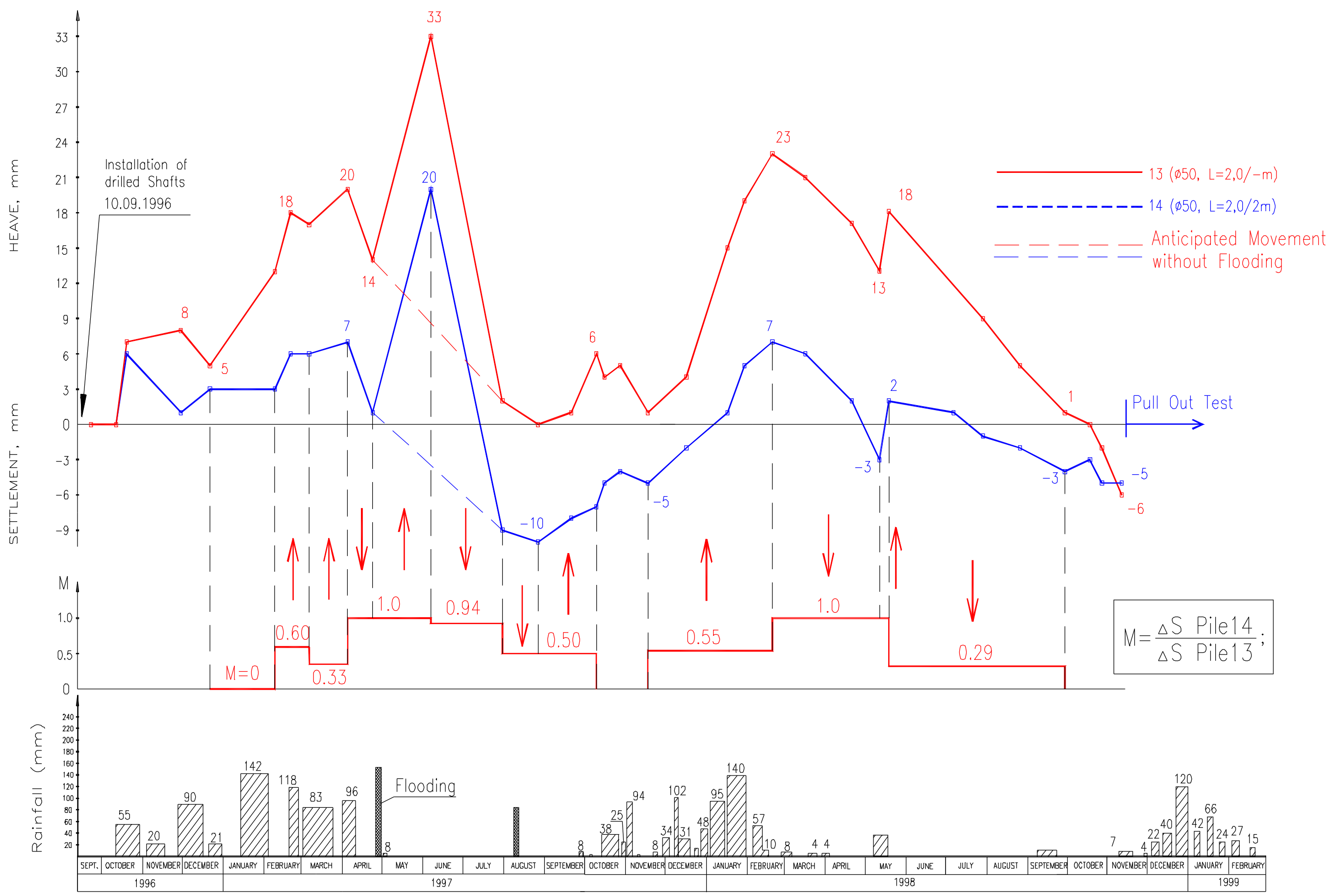

Figure 2. Vertical movement of piles 13 and 14 as a function of rainfall

5. CONCLUSIONS

For short, lightly-loaded piles installed in swelling soil there is a clear correlation between rainfall and movement of the pile head. In regions with swelling soils the seasonal variation in ground moisture due to rainfall can cause vertical displacements (well in excess of 20mm) which negate the benefits of a pile foundation and may even cause failure of such a foundation. By installing a slip-layer between a pile and the surrounding soil it is possible to significantly reduce heave forces which act on a pile and thereby protect the integrity of the piled foundation.

REFERENCES

Hazzan B Sh (2004) “Field behaviour of unloaded piles in swelling clay”, PhD thesis, University of Wolverhampton

Kulhawy F H and O’Rourke M (1980) “Observations on load tests for drilled shafts”, Drilled Piers and Caissons Workshop, Cornell University, Ithaca, USA.