Long-term tank displacement observations

Observation des déplacements à long terme d'un réservoir

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SYNOPSIS: At a liquid chemicals terminal at a port on the Adriatic Sea three groups of tanks were constructed. Due to the bad foundation conditions (more than 25 m of soft recent marine clayey sediments overlaid by 2 m of dredged material) the tanks were mounted on concrete ring footings or reinforced foundation slabs on the ground, improved by preloading. The results of settlement measurements during preloading, the first and subsequent loading and unloading are outlined and discussed.

INTRODUCTION

The lay-out of the terminal for liquid chemicals at a port on the Adriatic Coast is shown in Fig. 1. Steel and plastic cylindrical tanks were erected on very compressible soil in the period 1971-1985. The total installation consists of three units (marked I, II and III in Fig. 1), as follows:

I. Tank Nos. 101-110 (I.A) and Nos. 201-208 (I.B), constructed in the period 1971-1973 and mounted on ring footings on the soil, improved by preloading,

II. Tank Nos. R1-R4, erected in 1983, mounted on four separate reinforced concrete foundation slabs, and

III. Tank Nos. R5-R10, erected in 1985 on a single reinforced foundation slab on previously preloaded soil. Cross-sections showing the tanks, foundation structures, as well as the geotechnical profile are also given in Fig. 1.

SUBSOIL GEOTECHNICAL PROPERTIES

Recent littoral clayey sediments at the terminal area are, by origin, weathered Eocene flysh material. The solid flysh layers appear at a depth of about 60 m below sea-level and are covered by gravel-like deposits. Above them, clayey sediments extend from a level of about -28 m up to the former sea floor at a level of -0.5 to -2 m.

The fundamental geotechnical properties of the clayey sediments (marked 'c' on the geotechnical profile) are shown to the right of Fig. 1. As functions of depth are presented natural water content, plastic and liquid limits, shear strength as determined by vane tests, modulus of compressibility related to oedometer tests which correspond to natural primary pressures and the coefficient of permeability k.

Beside the tests mentioned above some triaxial shear and triaxial deformability tests were also performed on undisturbed samples 20 cm in height and 10 cm in diameter. The results of these tests are given in another reference (Sovinc & Vogrinčič 1974).

During the middle of 1971 the hydraulic fill (formed by dredging) was increased to a level of +1 m. This artificial sediment of very high compressibility and very low strength (marked 'b' in the geotechnical profile) had been partially squeezed out by frontal filling of weathered flysh material, which was used as the basis for further work. A new soil layer was thus formed, which was compacted by bulldozers. In the geotechnical profile this layer is marked 'a'. At the location of the group of tank Nos. 101-208 the top level of the embankment was at an elevation of +1 to +1.5 m, while at other parts of the terminal area the embankment height decreased to the surface of dredged material.

IMPROVEMENT OF SUBSOIL AND MEASURED SETTLEMENTS

In the following paragraphs the measured settlements, as functions of the method of building and time taken, will be given and discussed separately for groups of tanks I, II and III.

Group of tanks I (Nos. 101-110 and Nos. 201-208)
A detailed description of the improvement of the subsoil to prevent the rupture of soil under the tanks due to shear strength being exceeded and to reduce displacement is given in another reference (Sovinc & Vidmar 1973). To summarize, the applied method of soil improvement by preloading was as follows:

In August 1971, two preloading embankments were constructed with widths of 30 m (I.A), and 36 m (I.B) respectively and a height of 4.5-5 m. The embankment material of weathered flysh, was compacted by bulldozers, and had a unit weight of about 17.5 kN/m^3, loading the subsoil with a pressure of 79-87.5 kPa. The settlements beneath the preloading embankments were observed till February 1972. Afterwards, the flysh material used as preloading was removed, and the surface was levelled at an elevation of +2.5 m. During preloading embankment (I.A) settled about 1 m, and embankment (I.B), more than 1.5 m. To determine the amount of initial deviatoric displacements of the soil after the construction of the tanks, their time development and the effects of preloading, two tanks with a diameter of 8.53 m and a height of 8.96 m were mounted at the location of the terminal. They were positioned at an axial distance of 23 m on a gravel foundation 30 cm thick. Sixteen measuring points were welded on the lower section around the tanks and a further seventy points were placed around them

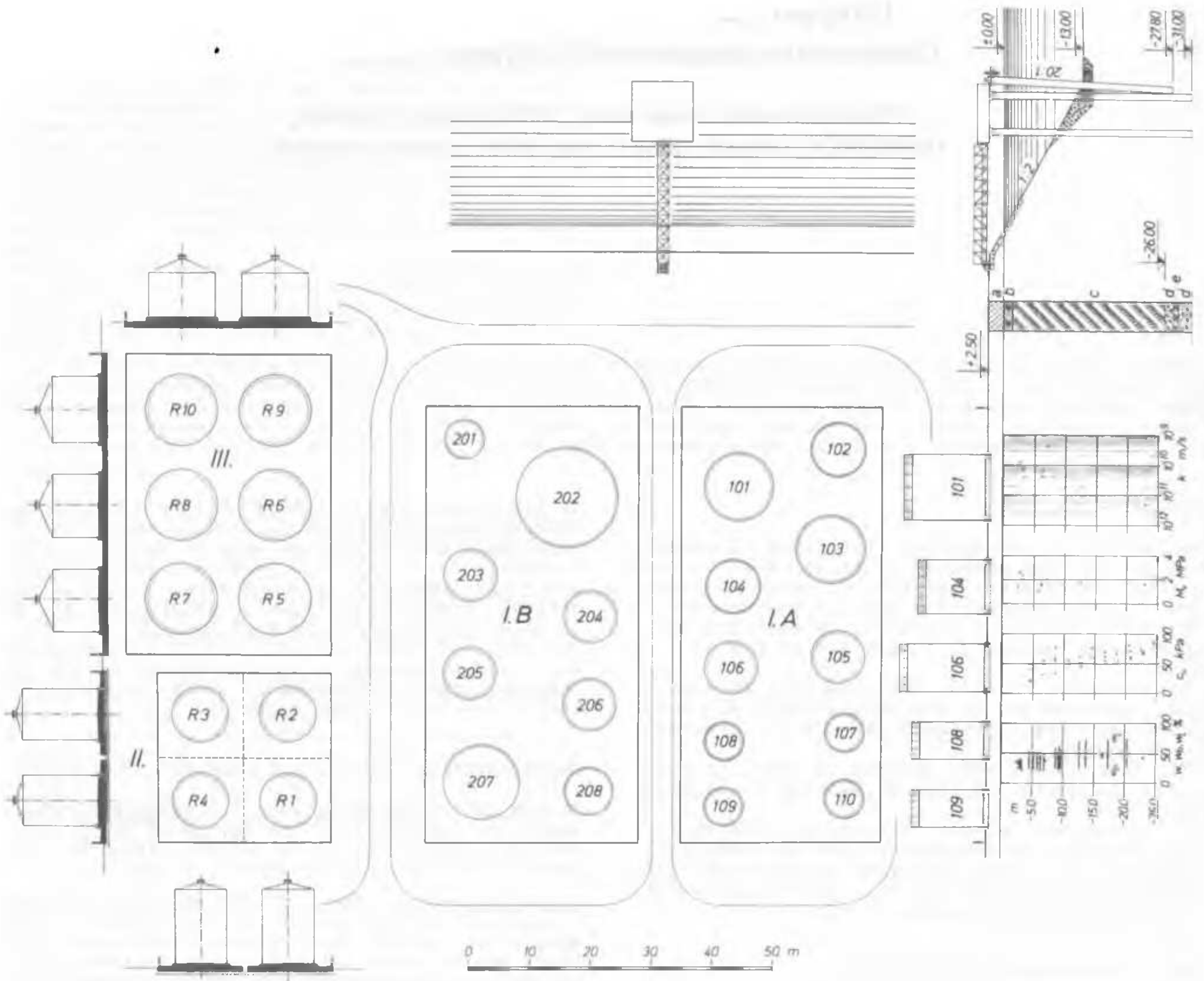

Figure 1. Site plan with cross-sections and geotechnical profile

at 1.5 m intervals from each other. The first tank was subjected to gradual loading in small stages interrupted by unloading and reloading phases, while the second tank was loaded quickly in one single stage to an equal final load. Further more, at each tank location temporarily movable tanks of the dimensions given above were erected to preload the soil again.

The average settlements on preloaded soil at the periphery of the tanks after some weeks of full load attained a value of 10-20 cm. In areas not preloaded, however, the values were 50-60 cm.

In November 1972, the water-load test started. The tanks were mounted on ring footings. Only the pipe conections were not fixed yet to allow different settlements. The registered settlements were between 10-12 cm.

The installation was finished at the end of 1972. Since 1973, when the tanks were first used, settlements were measured on the periphery of the concrete ring footings. The average settlements for the period 1973-1985 are given in Fig. 2 for the group of tank Nos. 101-110, whereas similar time plots for the group of tank Nos. 201-208 are left out due to lack of space. Beside the current number of tanks, the table also shows their diameter and height. The fact that the tanks were frequently filled and emptied allows the assumption that they were filled with liquid chemicals of unit weight 17 kN/m^3 for an average 75% of the time.

Group of tanks II (Nos. R1 - R4)

In August 1971, on the west side of the group of tanks I, the construction was completed of an embankment of weathered flysh at an elevation of +2.5 m. Up till 1973, the embankment settled by about 50 cm, and in the period 1973-1983, by a further 15 cm. At this location under the weathered flysh layer 1.4 m thick the height of the artificial dredged sediments was approximately 2 m.

The tanks are 8.5 m in diameter and 12 m in height. The weight of each tank filled with liquid chemicals of unit weight 17 kN/m^3, including the weight of the foundation slab is, 13.9 MN.

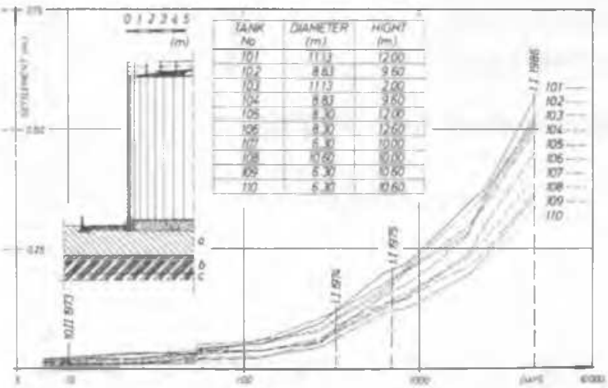

Figure 2. Observed settlements of tank group I

The tanks are made of plastic, and the roofs are interconnected by steel bridges. The tanks are erected symetrically on four square-formed concrete slabs with dimensions 14.3 x 14.3 m, entirely separate from each other.

Measuring points Nos. 1-20 for settlement observations were placed at the corners of all four slabs. Measurements were made frequently during the water test and were rarely repeated during the time the tanks were used. Since the settlements at all corner points for all four separate slabs are very similar, only the results for the foundation slab under tank No. 3 are given in Fig. 3. Because all four tanks were filled with chemicals and emptied almost to an equal level simultaneously, the intensity of soil pressure was supposed to be equal under all of them. In addition, any three tanks would equally affect settlement of the fourth. The inclination of the slabs in respect to their centre as a function of time is given in Fig. 4. As shown, inclinations after each filling of the tanks increased. However, their intensity, as time elapsed, decreased.

Group of tanks III (Nos. R5 - R10)

In 1971, the surface at the location of tanks R5 - R10 was levelled at an elevation +2.5 m. Two years later the embankment was raised to an elevation of +3 m for a short period, and later lowered again to an elevation of +2.5 m. Afterwards, the measurement of settlements commenced. 35 cm of settlement was registered up till 1985. Under the embankment of weathered flysh 1.5 m in height there was a layer of dredged marine clay over 2 m thick.

Preloading of the surface at an elevation of +1.75 m began in December 1985. Dimensions of the preloading embankment and their alternation process are given in Fig. 5. Settlements of specially erected points 1-17, laid under the embankment, were observed until the middle of June 1986. Unfortunately, the soil was preloaded by the embankment for one month only, and therefore, initial distortional deformations had not yet reached its maximum. During a period of only 10 days the preloading embankment was removed, and the surface levelled at an elevation of +2 m once again. A single concrete slab with a rectangular form 34 x 50 m and an average thickness of 1.35 m was completed after one year, in June 1986.

The tanks are 11 m in diameter and 8.3 m high, with a volume of 750 m^3. The water loading test lasted from 5th June 1986 to 14th August 1986. After that period the tanks remained empty until 23rd October 1986. Since then, they have been frequently utilized. The filling procedure is given in the lower part of Fig. 5. The pressure kPa represents the total load of the tanks, including the foundation slab, on the subsoil. 12 measuring points were installed in the slab. Their positions are given in Fig. 5. For measuring points Nos. 22, 25, 28 and 31 observed settlements as a function of time and load are shown in the same diagram.

CONCLUSIONS

Many years of experience on the behaviour of cylindrical tanks erected on very compressible soil leads to some general conclusions, which are in accordance with detailed geotechnical analyses described by the authors elsewhere (see ref.). They refer to the actual case of building up a liquid chemical terminal on normally consolidated littoral marine clayey sediments.

1. Due to the frequent loading, unloading and reloading of tanks erected on soil of low permeability, distortional displacements represent a very important part of total settlement. Because the rather short service life of such structures is only a few decades most of the displacements

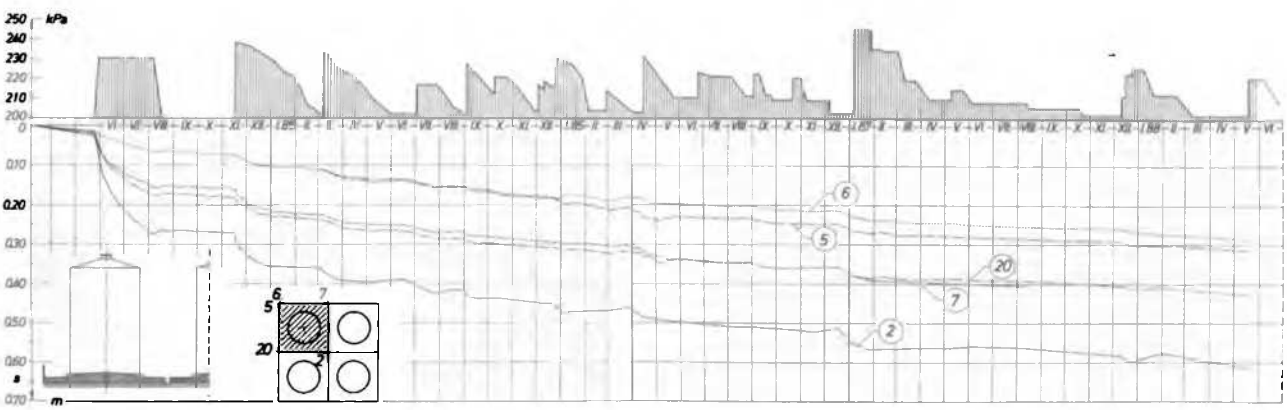

Figure 3. Observed settlements of one foundation slab of tank group II

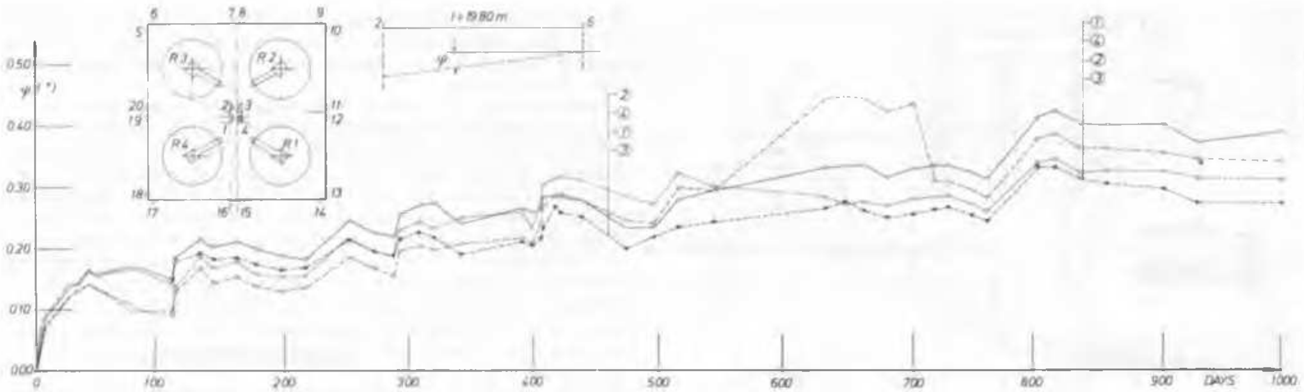

Figure 4. Slab inclination as a function of time

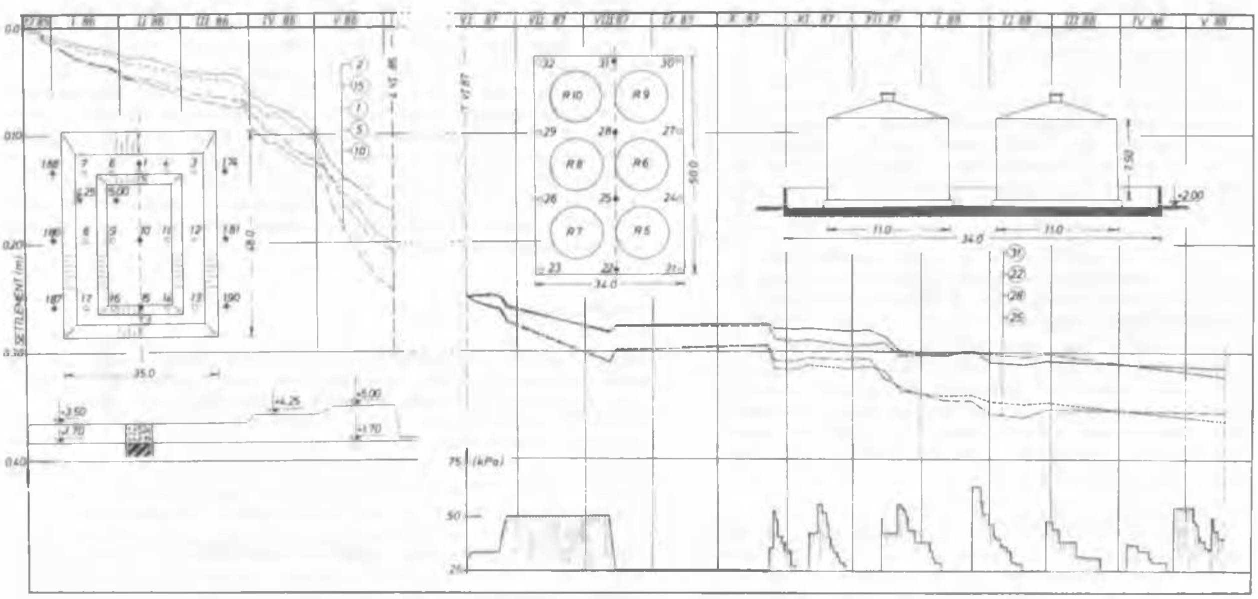

Figure 5. Observed settlements during preloading (left) and use (right) of tank group III

are expected to be of a deviatoric character. The preloading effect can be efficient, even if unassisted by drainage.

2. Deviatoric displacements depend on stress history: during subsequent unloading and reloading they are much lower than during initial loading.

3. According to field observations the deviatoric strain v. time plots regain, after unloading and reloading, the prolonged plot of the first loading.

4. During the initial loading of tanks with chemicals which have a unit weight greater than water (commonly used for test loading), a load corresponding to the test value is recommended.

5. Where highly compressible subsoil exists, flexible foundation structures are usually more economical, and are therefore also recommended.

REFERENCES

Sovinc, I. & Vogrinčič, G. (1974). Foundation of steel tanks by preloading (in Slovene). Proc. 4th Danube-European Conf.Soil Mech.Found.Engg, (1), 221-231, Bled.

Sovinc, I. & Vidmar, S. (1973). Preloading effects on deviatoric soil displacements. Proc. 8th Int.Conf.Soil Mech.Found.Engg, (1), 389-393, Moscow.

Suklje, L. & Sovinc, I. (1963). Foundation of cylindrical tanks on soil of low bearing capacity (in Serbo-Croatian). Gradjevinar, (5), 149-155, Zagreb.

Suklje, L. & Sovinc, I. (1963). An applied analyses of distortional displacements of normally consolidated clays. European Conf.Soil Mech.Found.Engg, (1), 193-198, Wiesbaden.