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Settlement of Multi-Story Buildings on Sand Fills

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SYNOPSIS The behaviour of two residential buildings with shallow foundations supported on sand fills with underlying soft alluvial deposits are discussed. Regular settlement measurements were taken for four and seven years on the foundations of the nine-storey and five-storey buildings respectively. Measured settlements have been compared with predictions based on the theory of one-dimensional consolidation. The factors that might have been responsible for the lower predicted settlement values are highlighted.

INTRODUCTION

In recent years geotechnical engineers often encounter construction problems due to poor soil condition. The need for soil improvement of a site becomes necessary when the soil is weak and unstable, but cannot be abandoned for the desired support and stability of the structure.

As a result of non availability of good firm lands to accommodate projected building development, swampy terrains and flood plains of rivers are reclaimed by hydraulic sand filling.

This paper describes the measurement of settlement of two structures in Kiev as well as the method used to predict settlements.

The building sites consist of up to 3.0m of sand fill over soft river alluvial deposits. Experience and laboratory test results indicated that long-term settlements were to be expected, however, largely due to economic reasons shallow foundations were adopted for the structures.

The walls of the buildings are made of burnt bricks and were designed with special emphasis on spatial stiffness in order to reduce differential settlements.

GROUND CONDITIONS

The buildings considered in this paper are located on the flood plain of River Dnepr within Kiev, Ukraine, which was reclaimed by sand filling.

A summary of the geotechnical properties of the alluvial deposits found on the case study sites before sand filling are given in Tables 1 and 2.

TABLE 1. Geotechnical properties of peaty deposits

Property	Unit	Type of Soil		
		Peat	Peaty loam	Peaty sandy loam
W	%	75	53	45
γ	kN/m^3	11.0	14.0	14.6
γ_s	kN/m^3	16.6	22.5	23.2
e	-	1.93	1.45	1.31
E	MPa	1.5	1.8	2.5
φ	Deg	20	17	22
c	kN/m^2	20.0	16.0	15.0
n	%	76	32	28

TABLE 2. Geotechnical properties of silty deposits

Property	Unit	Type of Soil		
		Silty loam	Silty sandy loam	Silty sand
W	%	46	32	18
γ	kN/m^3	14.5	15.1	16.3
γ_s	kN/m^3	23.5	25.0	26.2
e	-	1.39	1.20	0.92
E	MPa	1.0	3.0	5.5
φ	Deg	15	18	22
c	kN/m^2	14	12	8
n	%	29	18	15

W - moisture content; γ - bulk unit weight; γ_s - unit weight of solids; e - void ratio; E - modulus of deformation; φ - angle of internal friction; c - cohesion; n - loss on ignition.

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METHOD OF MEASUREMENT

During the construction of the buildings permanent reference points were cast into each structure around its perimeter at ground floor level. The reference points consisted of galvanized steel bolts cast into the concrete leaving only the heads exposed. All reference points were related to nearby benchmarks at the time of installation and subsequently after each new level.

The surveys covered the effective construction period and occupancy period.

CASE STUDIES

The foundations and soil conditions beneath the buildings are described individually:

1. Five-storey residential building

The building has dimensions of 85.0m x 13.0m on plan and is 17.5m high. The foundation of the building is in the form of precast reinforced concrete blocks which were laid in sand fill to form a strip footing about 2.0m above the alluvial deposits.

The alluvial deposits are predominantly made up of fine water saturated silty sand which at the upper part is underlain by a lens of peaty sandy loam. At a depth of 5.0 - 8.0m below the foundation footing, two layers of peat as well as silty and peaty loam with a total thickness of about 1.8m are located. These deposits are underlain by silty sand.

The footing pressure of the strip foundation is not more than 0.2MPa and observation of settlement commenced immediately after the foundation of the building was placed. The load-time settlement relationship for the maximum and minimum settlements are shown in Fig. 1.

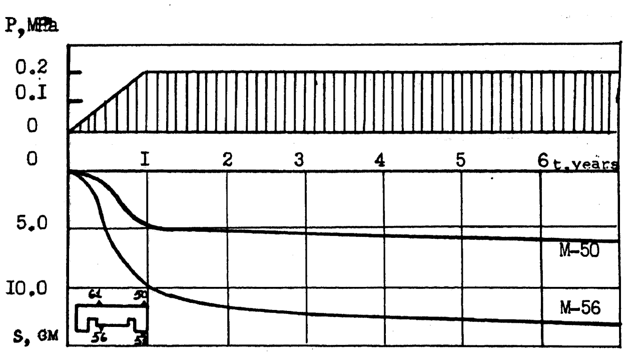

Fig. 1. Time-settlement curves for a 5-storey building on strip foundation.

2. Nine-storey residential building

This building with dimensions of 90.0m x 12.0m on plan and 27.5m high was designed and constructed on a raft foundation bearing on a layer of sand fill about 2.0m above alluvial deposits.

The alluvial deposits are made up of silty sandy loam which at a depth of 5.0 - 6.0m from the footing of the raft is underlain by a 0.5 - 2.0m thick layer of peaty loam. The peaty loam is underlain by silty sand.

The bearing pressure of the raft is not more than 0.2MPa and observation of settlement commenced immediately after the placement of the foundation. The load-time settlement relationship for the maximum and minimum settlements are shown in Fig. 2.

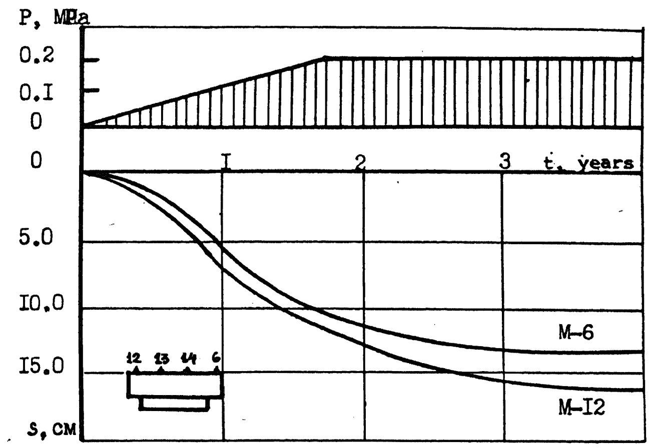

Fig. 2. Time-settlement curves for a 9-storey building on raft foundation.

PREDICTED SETTLEMENTS

Many methods have been proposed to predict time dependent settlements of structures. However, some of the methods which are used in practice (Florin, 1948; Tsytovich, 1963; Amaryan, 1967), were adopted in calculations of settlement of several structures founded on multi-layered bases (Osinubi, 1989).

An analysis of the results obtained by using the above mentioned methods showed, that all the computed settlement values were comparable. However, the method which takes into consideration the gradual loading of the base (Florin, 1948), gave a true picture of the settlement pattern especially during the construction period. The other methods assumed that the footing pressures were applied instantaneously.

The equation used to compute time dependent settlement (Florin, 1948) is given as:

$$s_t = \frac{2\alpha m_v h^3}{c_v}\left[\frac{c_v . t}{h^2} - \frac{1}{3} + \frac{1}{3}\exp(-Mt)\right] \quad (1)$$

where α - intensity of load application, kPa/year

m_v - coefficient of volume change, m^2/kN

h - thickness of compressible layer, m

c_v - coefficient of consolidation, $m^2/year$

t - time, year

$M = \frac{\pi^2 c_v}{4h^2}$, 1/year

Settlement values for any given time were computed by applying equation (1) to the different compressible soils in the base and adding the values obtained. The summary of some measured settlement values as well as computed values are given in Table 3.

TABLE 3. Comparison of observed and measured settlements

Case Study	Maximum settlement (cm)		Maximum differential settlement (cm)
	Measured	Computed	
1	13.3	10.5	7.3
2	15.8	13.4	2.8

It should be stressed that the two case studies presented in this paper cannot be considered as classic examples on which to base conclusions concerning the accuracy of the method of computation considered above. This is so because some of the alluvial deposits have erratic pattern of stratification and this implies that the strata concerned are heterogeneous in content. It should be noted that the strata were only fairly even. Furthermore, it is possible that deformations occuring in the alluvial deposits have allowed greater horizontal strains (and hence vertical settlements) to take place in the sand fill than otherwise would have been the case, if the sand fill had rested on more rigid strata.

DISCUSSION

In general, the maximum rates of settlement occured during construction and decreased to small rates after about two years for the cases considered. Also 44.3 - 71.4% of the maximum observed settlements took place during the construction period. The initial movements which led to the high rates of settlements were due to the near surface compaction of loose material as well as the footing pressure being more than the preconsolidation pressure of the alluvial deposits.

Settlement values computed by using equation (1) which is based on the theory of one-dimensional consolidation are about 15 - 21% lower than the observed values. The difference between the measured and computed values might be due to the drainage behaviour of alluvial deposits as compared with oedometer test samples (Rowe, 1968, 1972), sample disturbance (Terzaghi, 1941; Rutledge, 1944; Schmertmann, 1953, 1955) and lastly secondary consolidation (Foss, 1969; Adachi et al., 1986) which was not considered in the computations.

The observed differential settlements, 46.4 - 68.5% of which occurred during construction, do not reflect foundation type but indicate a general change across the sites. Also damage to the buildings which are minimal reflected differential settlement and was not connected with foundation type.

The settlement pattern of the five-storey building on strip foundation shows that it has the tendency to settle further whereas the time-settlement curves for the nine-storey building on raft has levelled up.

CONCLUSION

The application of equation (1), which assumes a gradual increase of pressure on the base, for the computation of time-dependent settlements of the buildings with multi-layered bases considered in this paper gave values that fairly closely agreed with measured settlements. Irrespective of the lesser computed values which might be due to the factors enumerated above, the equation can be used to compute approximate settlements of structures.

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