2nd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,
28-30 May 2009, Near East University, Nicosia, North Cyprus

The creeping shores of the Golden Horn

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KEYWORDS: Pore pressure dissipation, creep, slope stability

ABSTRACT: In a soft clay layer overlain by a thick man made ground layer, as in the case of the Unkapanı shores of the Golden Horn, excess pore pressures have remained for long periods and the soft clay layer has hardly undergone few volumetric deformations. Along the shores of the Golden Horn such creep of the soil towards the sea has been detected at more than 40 mm in the last 26 months. The measurements of those movements are examined in this paper. Our research points out that the local failure of a soil element or of a particular layer differs from the general failure of the soil mass. Furthermore, the large masses of unfailed soil which overlie the soft layer along the shores of the Golden Horn delay the general failure of the slopes. We conclude that the shear strains producing excessive pore pressures is the cause of the creep observed. Because a proper solution still need to be found for a sustainable stability of the area, it is necessary to continue with the measurements of the Golden Horn's creeping shores.

1 INTRODUCTION

In general the word creep is to mean that "very gradual out of place slip" or in geology "a gradual slipping of disintegrated rock due to stress, atmospheric changes, etc. in a scree" (New Webster Dictonary). More specifically, in geology, "Creep is downslope movement of particles that occurs on every slope covered with loose, weathered material" (Encyclopeadia Britanica). Terzaghi, Peck & Mesri (1996) further define creep as "shear strains that develop at constant external shear stresses".

Along the shores of the Golden Horn the creep of the soil towards the sea has been more than 40 mm in the last 26 months. The seat of the movement is generally overlain by a thick man made layer. The measurements of those movements are examined in this paper.

2 SOIL PROFILE

Over the centuries, the detritus brought by Alibey, Kağıthane and other creeks, heavy industrial and domestic waste, and uncontrolled fills have drastically changed almost the entire cross section of the Golden Horn. The typical soil profile of the area currently consists of loose or medium dense artificial fills and soft clay deposits which are underlain by a sloping bedrock. In the central part of the Golden Horn, 30 m deep bowl shaped rock base is filled with almost liquid like soft clay.

Artificial fills overlie marine deposits along the shores of the Golden Horn. They contain boulders, gravel, sand, silt, shells, wood, pieces of concrete and mortar, and all kinds of city debris. In fact, most of the valleys of the old city had been filled with every sort of material especially during the Roman times. It is difficult, thus, to determine the engineering characteristics of such fills. Furthermore, in many locations, the sedimentary layers which are found under the artificial fill consist of large amounts of organic matter and shells (Toğrol et al, 1986; Toğrol, 2001).

The thickness of the man made fill is over 40 m along the south shore and over 30 m along the north shore on the axis of New Galata Bridge. The fill's thickness is 46 meters in borehole No.BH3 along the south shore and 29 m in borehole No.BH11 as well as more than 35 m in the near shore boring No.BH10 along the north shore on the axis of the Metro Crossing. The thickness of the fill decreases with increasing distance from the shore. Man made fill is underlain by sedimentary layers which are described as light grey to dark grey fat organic silty clay of marine origin.

3 GEOLOGY

The first geological map of the old city and the Golden Horn area was prepared by Chaput (1936). The area was later studied by Sayar and Sayar (1962). They have found that the area consists of Paleozoic (Upper Devonian) greywacks as well as fine micaceous sandstones and shales which were overlain uncomformably by Sarmatian sand, clay, marl and limestone deposits.

Marine deposits along the shores of the Golden Horn have been found between the depths of 14.40 m and 18.00 m at a boring drilled 250 m inside the shore, near Eminönü, and in another boring on Atatürk Boulevard, 750 m inside the shore. Marine deposits might have been overlooked in previous studies since the coastline has been greatly changed over the years.

An investigation originally aimed to study the time of the Mediterranean-Black Sea connection after glaciation also provided valuable information concerning the properties of the sediments (Meriç, 1990). Meriç examined samples recovered from Metro and New Galata Bridge borings for their sedimentary, paleontologic, and physical properties. According to his findings the first marine influence probably began 7400 +/- 1300 years ago and marine conditions were established around 5700 +/- 1800 years ago. Meriç (1990) concludes that a continental environment prevailed in the Istanbul area prior to the opening of the Bosphorus. The Bosphorus area was then largely occupied by meandering river valleys draining the region to the north. The faults that previously affected the Paleozoic basement appear to have defined the course of those river valleys. The Black Sea was a closed lake before the last sea level rise.

The geotechnical problems involved when building along the shores of the Golden Horn have only occasionally been appreciated in the past. Subsidence, lateral movements, and large scale slides have been common features of the Golden Horn for centuries now. A few, but reliable records of those settlements are given by various authors (i.e. Peynircioğlu, 1961, 1962, 1975: Durgunoğlu & Akşit, 1978; Aksoy, 1982)

4 SETTLEMENT AND CREEP

Design of a foundation starts by ascertaining that it will not reach an ultimate limit state. Ensuring that the settlement of the foundation will be within the acceptable limits. Excessive settlements under working loads very often limit the serviceability of the structure. Estimation of the total settlement usually consists of two components: immediate undrained settlement, and consolidation settlement.

Calculation of long term settlements is based on an elastic analysis to estimate the change in total vertical stress. The change in total stress is equated to the change in vertical effective stress which causes consolidation of the soil.

Consolidation settlement is accompanied with the dissipation of excess pore pressures. Settlement due to consolidation is estimated by relating the change in vertical stress to the change in corresponding vertical strain. Such a procedure ignores the fact that the transfer from excess pore pressure to effective stress is in effect the actual cause of the consolidation settlement. When dissipation of pore pressure is obstructed the consolidation procedure delays and extends over a larger time span. Contained or delayed pore water pressure dissipation thus causes slow movement of soil masses.

The undrained effective stress path in the q-p diagram [where q=σ_1-σ_3 and p=$\frac{1}{3}(\sigma_1+\sigma_2+\sigma_3)$, follows the effective stress changes, in undrained loading, even though the total stress changes are different (Lancellotta, 1995). Once the effective stress path has passed through the initial yield surface yielding elements of soil have lower stiffness than the surrounding soil. It is assumed that the underlying deep bed of soft clay along the shores of the Golden Horn on which the made ground is placed has initially been loaded in an undrained manner.

Höeg et al (1969) carried field load tests on a soft quick clay and took a continuous record of excess pore pressures and settlements. Their conclusion states that "After critical surface load was reached, there was a pronounced increase in the rate of pressure build-up which was postulated to be a direct consequence of local shear stresses under the test fill exceeding the undrained clay strength." This shearing is accompanied by the generation of pore water pressures. If the load is kept constant the excess pore pressures dissipate, and further strains recur as the effective stress in the soil increase.

In foundation design it is envisaged that foundation soil will not reach an ultimate limit state, that is, it will not collapse under the applied loads. However, it is also necessary to ensure that the foundation does not become so much deformed under working loads, even without actually collapsing. In this context both the amount and rate of deformation are important. When the dissipation of pore water pressure is blocked or delayed soil elements which have already reached to their undrained strength create a zone of failure. The gradual movement of the soil masses -- it could be coined as yielding in critical state sense-- when shear strains developing under constant shear stresses is identified as creeping.

The local failure of a soil element or of a particular layer differs from the general failure of the soil mass. To reach the stage of general failure it should be necessary for all the soil elements in the soil mass have reached the critical state. Until that condition occurs, local failures and local deformations will be contained in a sense supported by the surrounding unfailed soil.

In the soft clay layer overlain by a thick made ground layer, as on the shores of the Golden Horn, excess pore pressures remain for long periods and the soft clay layer has hardly undergone any volumetric deformations.

5 MEASUREMENTS

Four inclinometers are installed at the Unkapanı shore of the newly designed Metro Crossing. INCL-K-03 and INCL-K-05 at 15 meters to the shore line, INCL-K-O4 35 m and INCL-K-O6 70 m to the shore line. The length of inclinometers is in INCL-K-03, 30 m, in INCL-K-04, 70 m, in INCL-K-05, 74m., and in INCL-K-06 75.00 m. Large deformations are observed in the inclinometers (Table 1).

When movement vectors are placed on the plan the prevailing direction is found not perpendicular to the shore line but rather slightly twisted towards the eastern direction where the sea bottom profile dips towards Kasımpaşa.

In Tables 2, 3, 4, and 5 the upper and lower elevations of layers, average Standard Penetration values depths of displacement measurements (m), displacements (mm), and directions of displacements are given for inclinometers 03, 04, 05 and 06. Soil descriptions are left as they were determined at the field.

Table 1. Measured deformations

Inclinometer	Depth (m)	A-axis (cm)	B-axis (cm)	Total movement (cm)
INCL-K03 (12.2.2007 21.4.2009)	3.00	+2.573	-2.921	3.892
	9.00	+1.337	-2.640	2.959
	10.00	+3.512	-2.145	4.115
	21.00	+0.713	-1.701	1.844
	29.00	-1.374	-1.207	1.829
INCL-K-04 (12.2.2007 21.4.2009)	6.00	+1.642	+1.857	2.479
	7.00	+3.657	+1.910	4.126
	17.00	+0.398	-0.025	0.389
	30.00	+0.031	-0.163	0.167
	31.00	+0.193	+0.176	0.261
INCL-K-05 (2.6.2008 - 21.4.2009)	0.00	+0.315	-1.614	1.614
INCL-K-06 (2.6.2008 21.4.2009)	0.00	+0.276	-0.749	0.798
	2.00	+0.258	-0.734	0.778
	10.00	+0.193	-0.742	0.767
	11.00	+0.285	-0.652	0.712
	12.00	+0.190	-0.717	0.742
	13.00	+0.150	-0.762	0.777
	18.00	+0.147	-0.677	0.693
	20.00	+0.190	-0.659	0.686
	31.00	+0.060	-0.536	0.539
	32.00	+0.060	-0.524	0.527
	35.00	+0.110	-0.487	0.499

Table 2. Soil profile and direction of displacements – INCL-K-03

Upper/lower elevation of layer (m)	Soil	Average N in the layer	Displacement		
			Elevation (m)	Displacement (mm)	Direction
+1.54	Ground level				
	Man made	18	-1.46	39	NE
			-7.46	30	NE
			-8.47	41	NE
-15.96					
	Man made	26	-19.46	18	NE
-22.46					
	Poorly graded gravel	27			
-27.46					
	Poorly graded sand	35	-27.46	18	S
-32.46					
	Poorly graded sand	33			
-37.46					
	Clayey sand	7			
-40.46					
	Fat clay	13			
-44.46					
	Gravely fat clay	6			
-51.46					
	Fat clay	19			
-54.46					
	Clayey gravel	56			
-59.46					
	Sandstone				
-64.76					

Table 3. Soil profile and direction of displacements – INCL-K-04

Upper/lower elevation of layer (m)	**Soil**	**Average N in the layer**	**Displacement**		
			Elevation (m)	**Displacement (mm)**	**Direction**
+2.21	Ground level				
	Man made	18	-3.79	25	N
			-4.79	41	N
-4.79					
	Poorly graded gravel	20			
-12.79					
	Well graded sand	16	-14.79	4	NE
			-27.79	2	NE
			-28.79	3	N
-35.79					
	Silty sand	24			
-40.79					
	Fat clay	4			
-46.79					
	Fat clay	7			
-56.79					
	Clayey sand	> 50			
-63.84					
	Sandstone				
-77.79					

Table 4. Soil profile and direction of displacements – INCL-K-05

Upper/lower elevation of layer (m)	**Soil**	**Average N in the layer**	**Displacement**		
			Elevation (m)	**Displacement (mm)**	**Direction**
+2.00	Ground level	-	+2.00	16	NE
	Man made	9			
-6.96					
	Man made	11			
-12.96					
	Man made	19			
-44.46					
	Clay	12			
-48.46					
	Clay	4			
-57.96					
	Clayey gravel	43			
59.46					
	Clayey sand	> 50			
-61.21					
	Sandstone				
-72.96					

Table 5. Soil profile and direction of displacements – INCL-K-06

Upper/lower elevation of layer (m)	Soil	Average N in the layer	Displacement		
			Elevation (m)	Displacement (mm)	Direction
+2.82	Ground level	-	+2.82	9	NE
	Top soil				
+2.32					
	Man made	11	+0.82	8	NE
			-7.18	8	NE
			-8.18	7	NE
			-9.18	7	NE
			-10.18	8	NE
			-15.18	7	NE
			-17.18	7	NE
			-28.18	5	NE
			-29.18	5	NE
			-32.18	5	NE
-34.18					
	Sand	11			
-43.18					
	Siltstone	44			
-45.18					
	Sandstone	77			
-62.18					

Soft clay layers at inclinometer locations with very low SPT blow counts at greater depths are discernible in Figures 1 to 4.

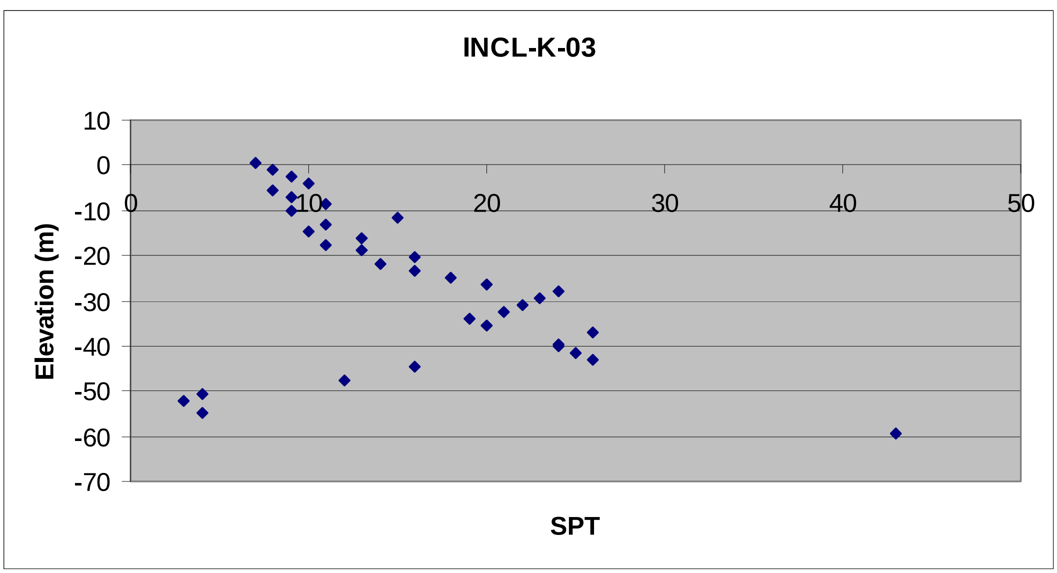

Figure 1. Inclinometer locations with SPT blow counts – INCL-K-03

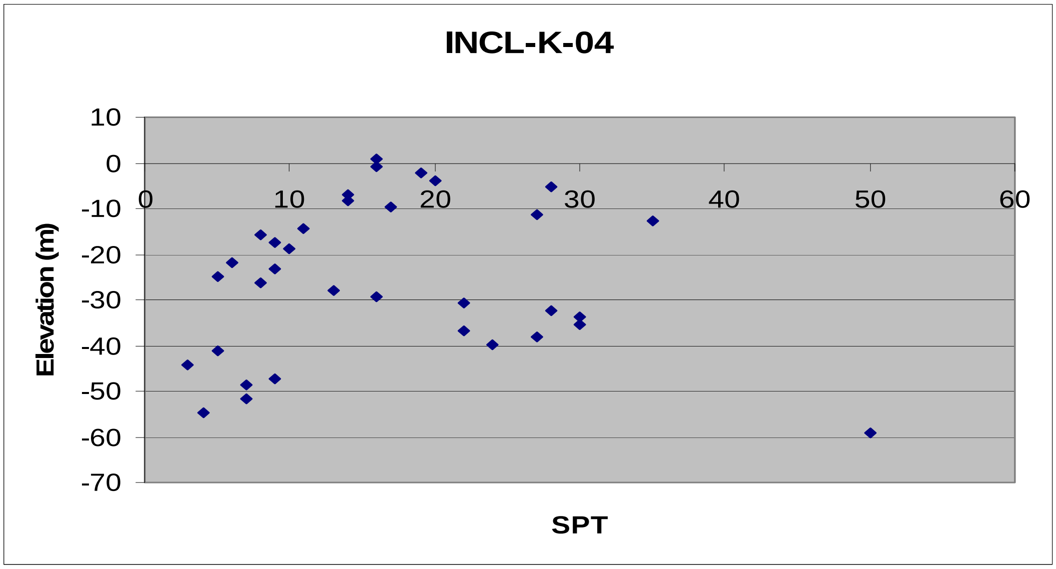

Figure 2. Inclinometer locations with SPT blow counts – INCL-K-04

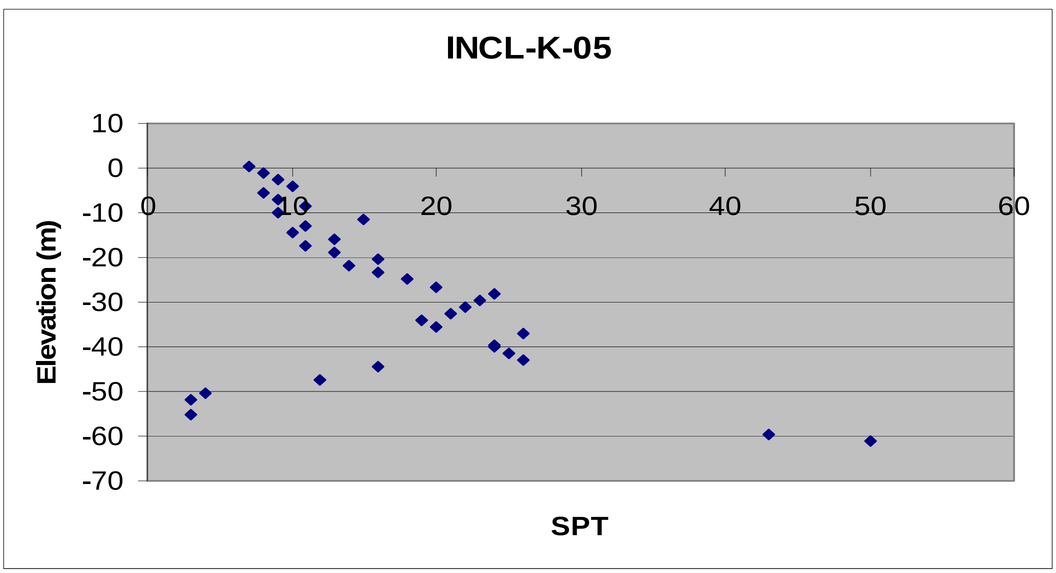

Figure 3. Inclinometer locations with SPT blow counts – INCL-K-05

6 REMEDY

Loading the toe of the creeping slopes is considered as a remedial measure. Apart from environmental considerations this option would be difficult to execute because of the presence of very soft layers at the toe of the slope. Hence a proper solution needs to be found for a sustainable stability of the area. In the meantime it would be necessary to continue measuring the creep of the Golden Horn.

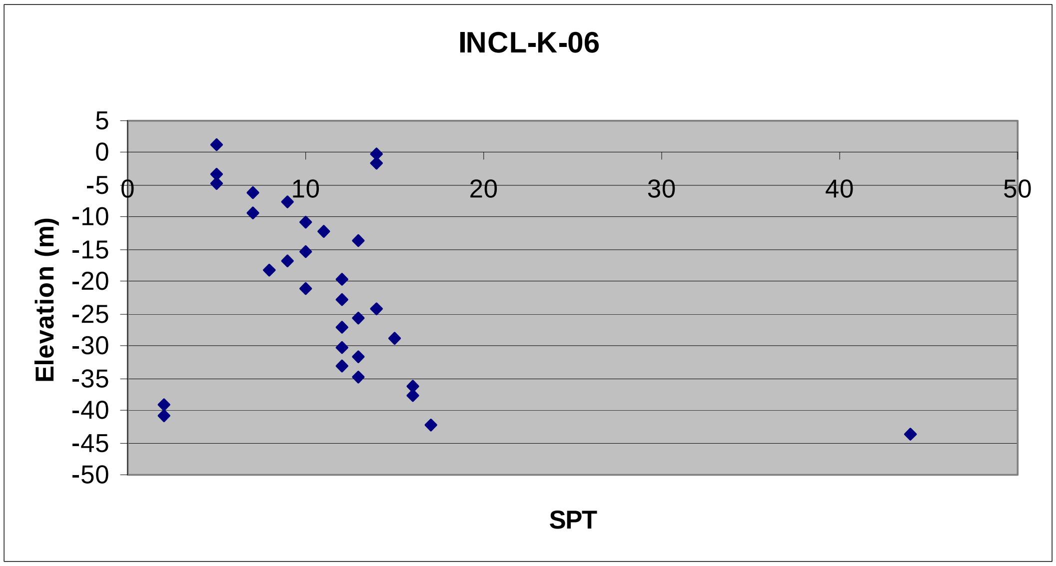

Figure 4. Inclinometer locations with SPT blow counts – INCL-K-06

7 SUMMARY AND CONCLUSION

Measurements of soil movement along the Unkapanı shores of the Golden Horn are examined. The existence of a slow but continuous movement has been detected. Soil profile at that location consists of a thick man made ground overlying the soft clay alluvium. It is concluded that the shear strains producing excessive pore pressures is the cause of the creep observed.

REFERENCES

Aksoy, İ.H. (1982) İstanbul'da tarihi yapılarda uygulanan temel sistemleri, (Foundations of historical buildings in Istanbul) Ph.D. Thesis, Istanbul Technical University, xııı+98 p., Istanbul.

Chaput, E. (1936) Voyages d'études géologiques et géomorphogénique en Turqui. Mém L'Inst France d'Archéol d'Istanbul, II, vııı+312 p., Paris

Durgunoğlu, T., H. Akşit (1978) Geotechnical evaluations for the Istanbul's Golden Horn, Journal of Boğaziçi University, 6, pp 36-56, Istanbul..

Höeg, K, O.B. Andersland, E.N.Rolfsen (1969) Undrained behaviour of quick clay under load tests at Åsrum Géotechnique, 19, No.1, pp.101-115.

Lancellotta, R. (1995) Geotechnical Engineering, A.A.Balkema, p.436.

Meriç, E.(ed) (1990) İstanbul Boğazı'nın güneyi ve Haliç'in Geç Kuvaterner (Holosen) dip tortulları, (Young Quaternary (Holocene) sediments of Istanbul Strait and Golden Horn) 114 pp, Ankara.

Peynircioğlu, H. (1961) Settlement of buildings in Istanbul Proc.5th ICSMFE,1, pp 771-778, Paris.

Peynircioğlu, H. (1962) Istanbul Haliç sahillerinin geotekniği Türkiye İnşaat Mühendisleri Odası ı. Teknik Kongresi, R.No.20, 24 pp, Ankara

Peynircioğlu, H. (1975) Haliç sahillerinin geotekniği (Geotechnical properties of the Golden Horn shores) İ.T.Ü. Haliç Sempozyumu, pp 391-401, Istanbul.

Sayar, M, C. Sayar (1962) Istanbul'un surlar içindeki kısmının jeolojisi, (Geology of the old city surrounded by the historical walls) İ.T.Ü. Maden Fakültesi, 26 p, 3 plts.Istanbul.

Terzaghi, K, R.B. Peck, G. Mesri (1996) Soil mechanics in engineering practice (Third ed) JohnWiley & Sons Inc, 549 p.

Toğrol, E., E. Güler, K. Özüdoğru, T. Ersoy, İ.H.Aksoy (1986) Haliç'in geoteknik sorunları ve çözüm yolları (Geotechnical problems of the Golden Horn and solutions) Boğaziçi University, 106 p, Istanbul.

Toğrol, E. (2001) Golden Horn: A historical survey of geotechnical investigations Proc.15th ICSMGE, 4, pp.2445-2470.