PRELOADING EFFECTS ON DEVIATORIC SOIL DISPLACEMENTS

DEPLACEMENTS DEVIATORIQUES EN FONCTION DE LA CHARGE PREALABLE

ВЛИЯНИЕ ПРЕДВАРИТЕЛЬНОГО НАГРУЖЕНИЯ НА ДЕФОРМАЦИИ ГРУНТА

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SYNOPSIS. Loading tests through tanks on recent litoral sediments are reported. The unloading and reloading effects onto the settlement development have been paid special attention. Owing to high thickness and small permeability of clayey deposits, the observed settlements are mainly of deviatoric character. They have been compared with observations on an undrained triaxial sample. Similarity in observed unloading and reloading effects promises the possibility of forcasting the field effects on the base of laboratory experiments.

INTRODUCTION

Recent litoral and lacustral, normally consolidated clayey and silty depositsexhibitimportant viscous deformability. Nevertheless, they can take over loading by low industrial structures, storehouses, tanks and embankments provided that before the construction settlements were forced by preloading and vertical drainage; in this way reversibile displacements caused afterwards by the structure itself can efficiently be reduced. When, in the life-time of the structure, the prevailing part of displacements is expected to be of deviatoric character, the preloading effect can be efficient even if not supported by drainage.

In the terminal area of the harbour of Koper (Slovenia) steel tanks are being built up. From the original ground level -0,50 to -2,00 m down to a depth of - 28 m the soil consists of recent clayey and silty litoral sediments lying on varying sandy and gravely layers with thin clayey intercalations; in a depth of about - 60 m appears the firm base of Eocene flysh rocks. Some years ago, the area was hydraulicaly filled with litoral sediments up to the level of + 1,00 m, and in summer of 1971, the weathered material of flysh rocks was raised up to the level + 2,50 m. The tanks are designed to be put on a 60 cm thick rock fill girded with rings of reinforced concrete.

Geotechnical features of recent litoral silty clays in the bay of Koper have been presented, in Fig. 1, by the following physical quantities as functions of the depth z:

a) natural water content w, plastic and liquid limits w_P and w_L ,

b) shear strength c_u determined by vane tests,

c) modulus of compressibility M_v related to oedometer tests at 1 kp cm^{-2} and

d) the corresponding coefficient of permeability k.

Between the levels + 1,00 and 2,50 m, the embankment has been compacted to a density of about 1.8 t/m^3. In comparison with natural layers the compressibility of the embankment is very small and its permeability negligible.

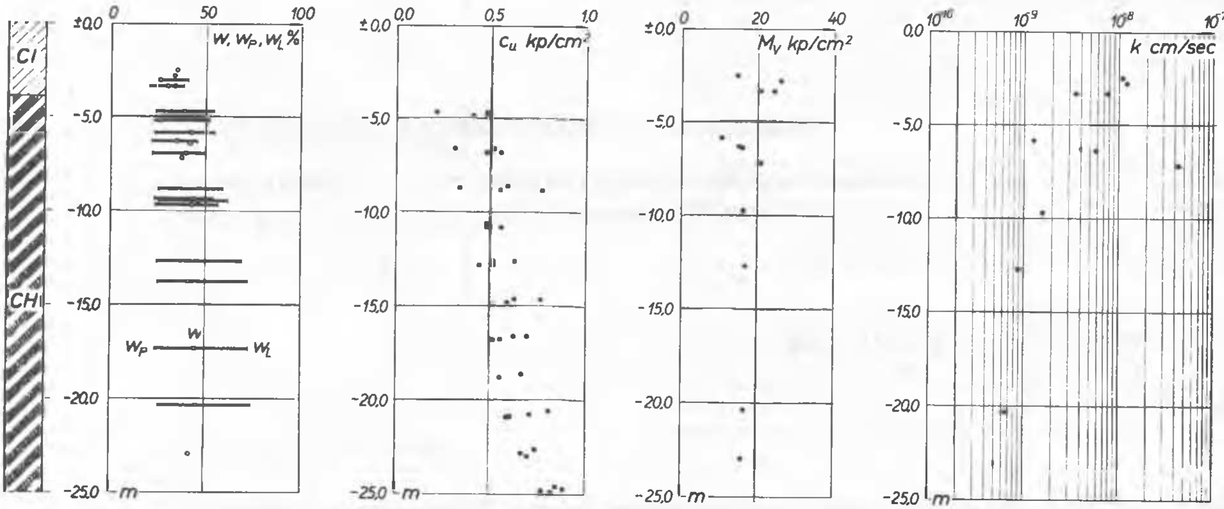

Fig. 1 Soil properties

FIELD INVESTIGATIONS

Owing to the great thickness of these recent clayey layers and their small permeability, the deviatoric part of the total displacements due to loading by tanks is expected to be very important. In order to establish their magnitude and development, extensive field measurements have been made. Two tanks of dia. 8.53 m and of a height of 8.96 m, have been mounted on the location of the terminal. They have been put, in axial distance of 23 m, on a gravely basis of a thickness of 30 cm. Sixteen measuring points have been welded on the lower periphery of tanks and further seventy points have been placed around the tanks at a distance of 1.50 m from each other. The first tank /R_1/ was subjected to a slow loading in small steps interrupted by unloading and reloading phases, while the second tank /R_2/ was loaded quickly in one single step to the same final load. The course of loading is listed below in Table I.

Table I

Tank	Loading step kp/cm²	Duration of the load application minutes	Duration of loading days
R_1	0,000 - 0,225	45	2
	0,225 - 0,450	65	7
	0,450 - 0,000	55	3
	0,000 - 0,450	45	8
	0,450 - 0,700	70	7
	0,700 - 0,900	14 45	91
	0,900 - 0,000	4320	28
R_2	0,000 - 0,900	1260	78
	0,900 - 0,000	4320	28

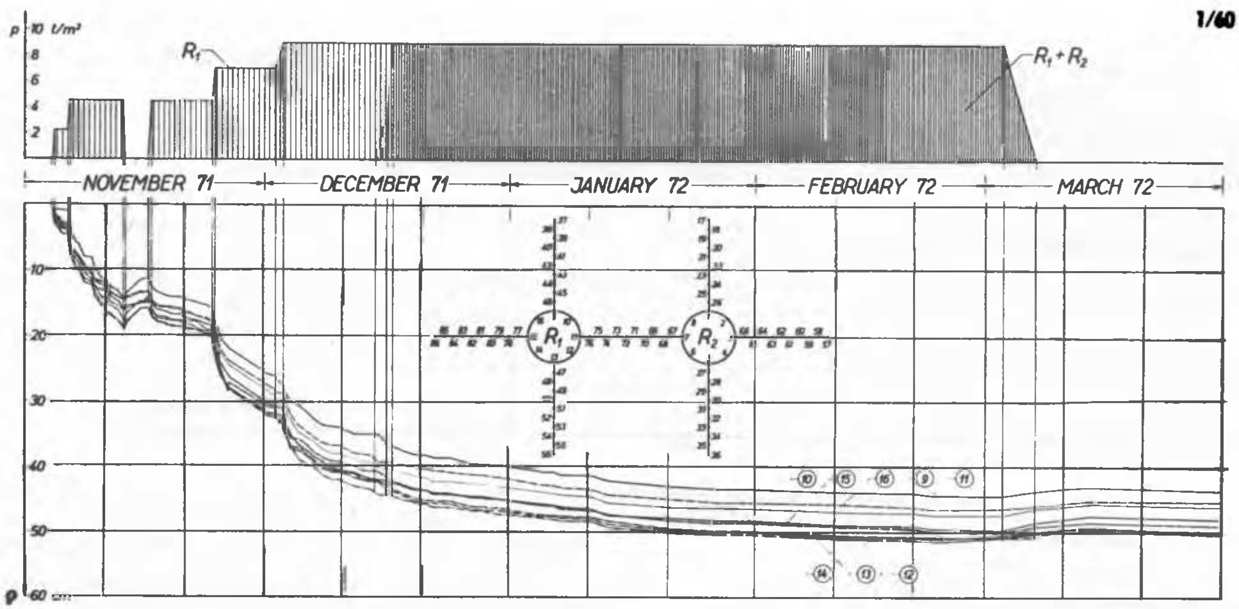

Fig. 2 Settlement and load versus plots for the peripheral points of the tank R_1

In Figures 2,3,4 and 5 the observed settlements are plotted versus time. The situation of measurement profiles is shown in Fig. 2. According to the test results, the average values of shear moduli have been computed by considering the ground as a homogeneous elastic half-space with Poisson's ratio $\nu = 0,50$. Moduli G corresponding to

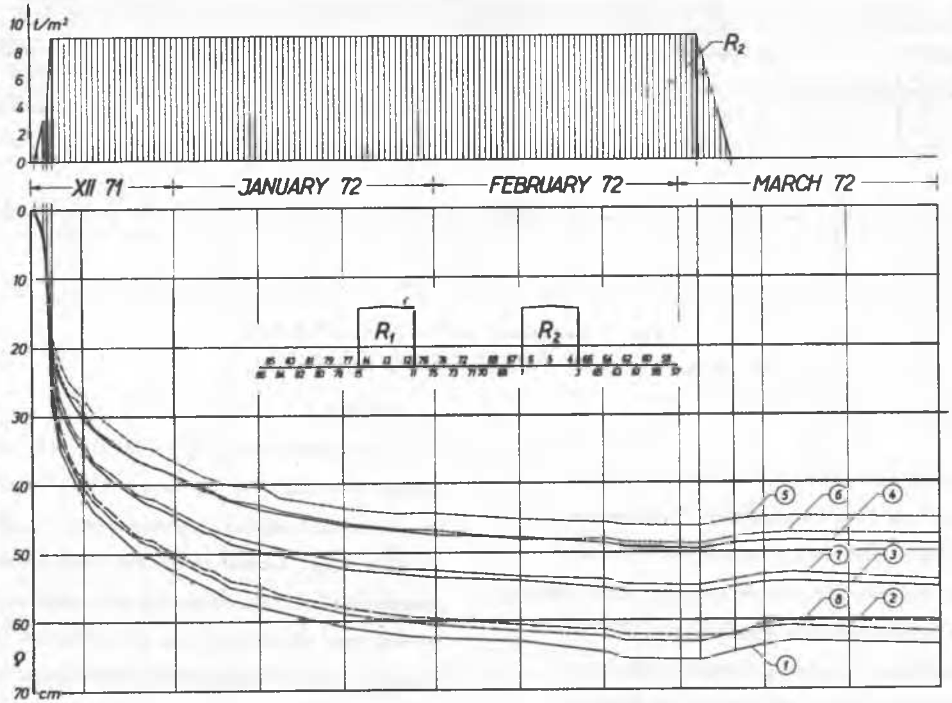

Fig. 3 Settlement and load versus time plots for the peripheral points of the tank R_2

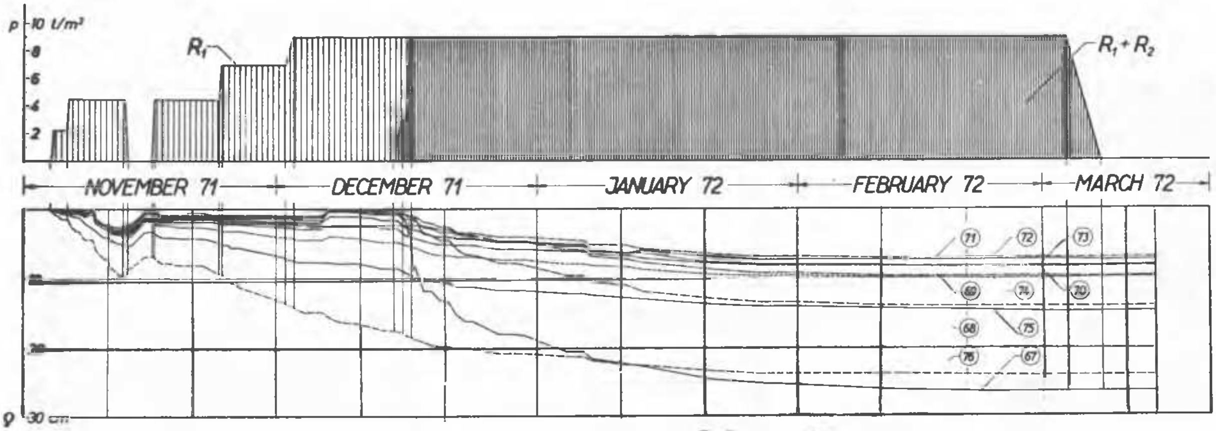

Fig. 4 Settlement and load versus time plots for the measuring points 67 to 76

average settlements observed on peripheral points of the tanks, have been plotted against time in Fig. 6: for the tank R_1 separately at loading, unloading and reloading.

In Fig. 7, similar plots are presented for respective measuring points 77, 78, and 66, 65, situated at distances 1.50 and 3.00 m from the tanks R_1 and R_2.

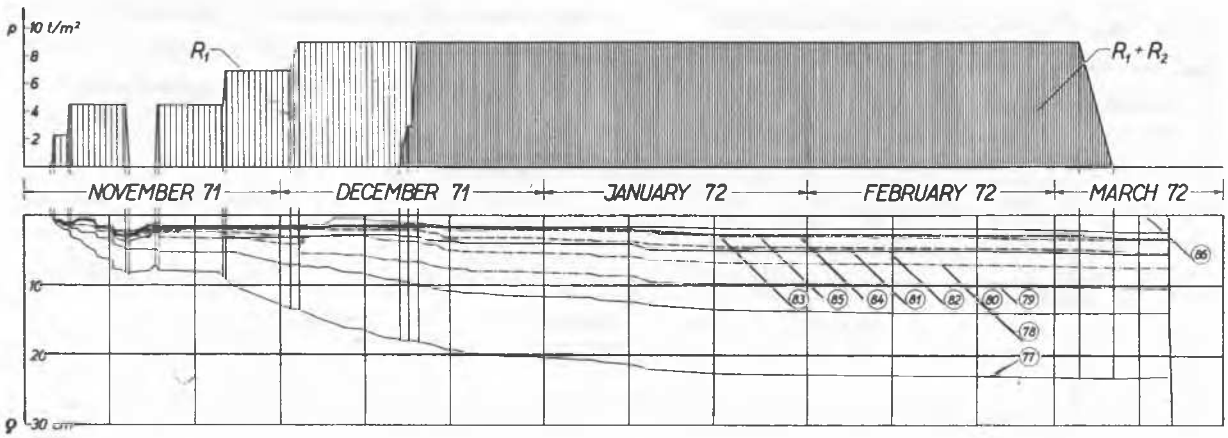

Fig. 5 Settlement and load versus time plots for the measuring points 77 to 86

LABORATORY TESTS

Laboratory test results presented in this section do not refer to the soil of our field investigations in Koper and cannot serve for an immediate comparison with field observations. They are related to an undisturbed triaxial sample of a clay of intermediate compressibility /CI/ from the Marsh of Ljubljana. They are presented in order to show similar preloading effects observed in the laboratory and in the field, and to indicate, in this way, the possibility of predicting field effects on the base of laboratory testing.

First, the specimen of 50 % water content, was consolidated at an all-around pressure of 0.7 kp/cm^2. Initial diameter and height of the sample were 10.14, and 21.15 cm resp. Consolidation was accelerated by a central drain. In the following load applications, the normal total octahedral stress of 0.7 kp/cm^2 was kept constant, while the deviatoric stress components varied in such a way that the tangents to the corresponding stress circles passed the origine of the coordinate system

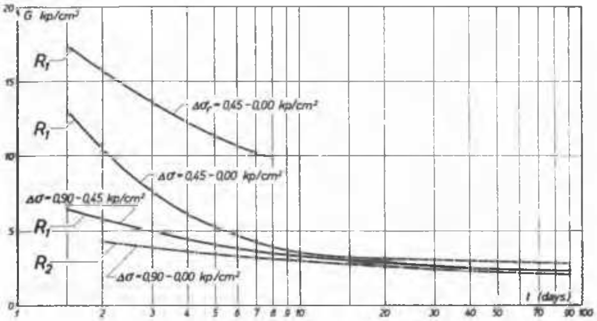

Fig. 6 Shear modulus versus time plots for peripheral points of tanks R_1 and R_2

/ σ , τ / under the slopes of $5^{\circ}30'$, 12°, 18^{0} and $2o^{\circ}$. At a slope of $5^{\circ}30'$ the stress state was assumed to correspond to the natural stress state; the sample was drained at the first application of this state. At all the subsequent stress states listed in Table II, the loading and the subsequent observation of deformations occurred in undrained conditions. At each loading step axial and volume strains were measured. In undrained steps pore-pressures were observed at the base of the sample.

In undrained steps no volume change has been observed. Consequently, the observed axial strains are only of deviatoric character. In Fig. 8, they are plotted versus time

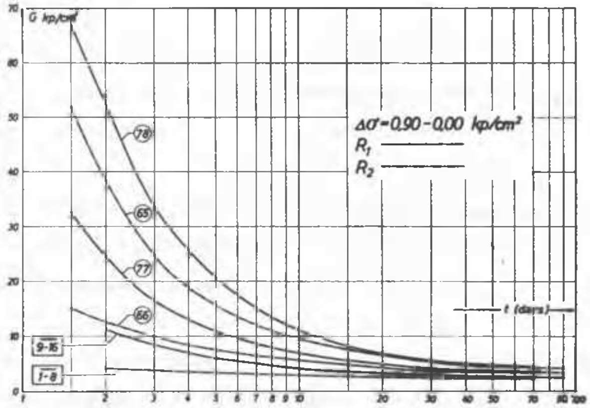

Fig. 7 Shear modulus versus time plots for outside measuring points

for each loading step separatly. In Fig. 9, the integrated plots $-2\ \varepsilon_3 = -2\ \varepsilon_2 = \varepsilon_1 = \varepsilon_{1/t/}$ are presented for respective loading step groups 3,4,5 and 6.7.8 /see Table II/. From these plots one can see that after the unloading, the reloading strain versus time regains the direction of the $\varepsilon = \varepsilon_{/t/}$ curve of the primary loading.

Table II

Loading step no	φ_m	Principal total stress σ_1 kp/cm²	σ_3	Drainage conditions
1	0	0,70	0,70	drained
2	5 °30′	0,80	0,66	consolidated
3	12°	0,91	0,595	undrained
4	5° 30′	0,80	0,66	
5	12°	0,91	0,595	
6	18°	1,02	0,54	
7	12°	0,91	0,595	
8	18°	1,02	0,54	
9	20°	1,06	0,52	

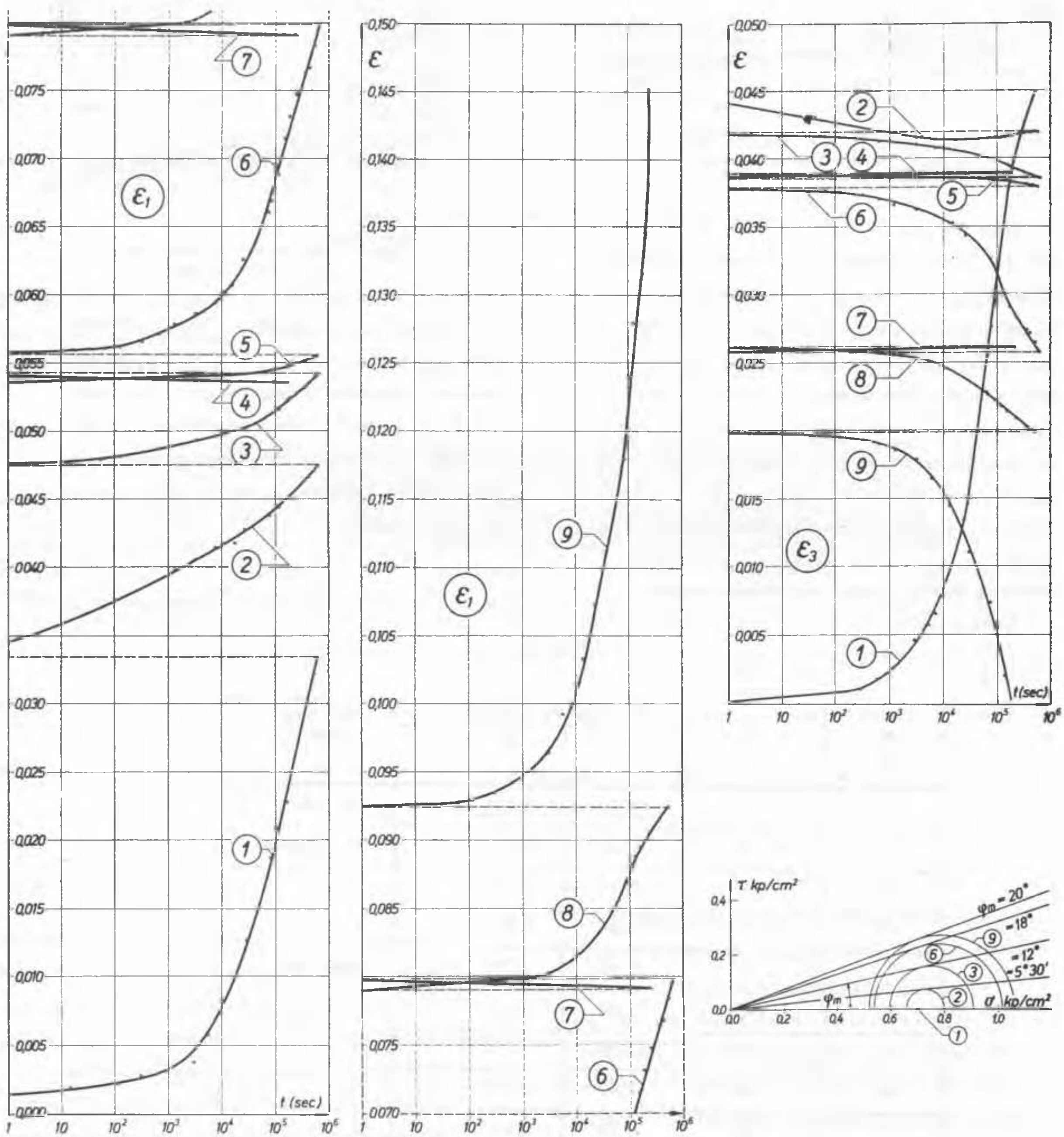

Fig. 8 Deviatoric strain versus time plots of an undrained triaxial sample

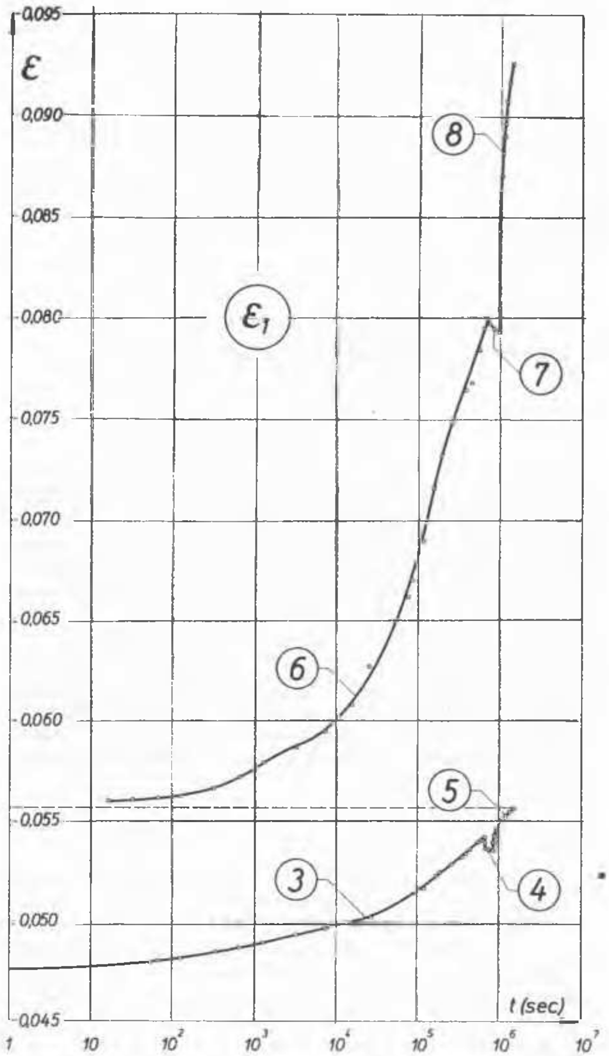

Fig. 9 Comparison of deviatoric strain versus time plots at first loading and reloading

CONCLUSIONS

Field and laboratory test results prove that the equivalent shear moduli G corresponding to the observed deviatoric displacements,

a) decrease with the increasing slope of the envelope of total-stress circles,

b) decrease in inverse proportion to time after the load application,

c) depend on the stress history; the moduli at unloading and reloading are much greater than at the first loading. The ratio between time-dependent strains at the first loading and reloading depends on the duration of the first loading. For the tank R_1, the ratio between the nine-day displacements at the first loading and eight-day displacements at reloading was about 1:0.35. In triaxial testing, the ratio between the seven-day strains at the first loading and thirteenday strains at reloading was about 1:0.33 for the step group 3, 4 and 5 /see Table II/ while the ratio between seven-day strains at the first loading and six-day strains at reloading in the step group 6,7,8 was about 1:0.55.

d) According to field and to laboratory observations, the deviatoric strain versus time plots regain, after unloading and reloading, the prolongated $\varepsilon = \varepsilon$ /t/ plot of the first loading.

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