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Investigation of Foundation Soil in the Seismic Area of Skopje

In connection with Water-power projects on the river Vardar the water level of this river shall be lowered of approx. 1 m. The author was entrusted in 1969 to investigate the influence of this water-table decrease on the properties of the foundation soils in the city area of Skopje, especially in case, that in the future another earthquake of a bigger intensity should take place. It is supposed that the cause of earthquakes in Skopje is the stress in the tectonic zone of Vardar, which lies between the more stable units of Pelagonesian and Serbo-Makedonian massive. The movement of the surface of the earth was prooved by repeated levelling from which vertical displacements till 160 mm were determined.

Foundation soils in Skopje consist prevailingly of sandy gravel with seams of sand and in a smaller degree are formed also by clayey soil with organic admixture. It must be mentioned that the big earthquake of July 1963 was preceeded in November 1962 by a fload of Vardar during which some parts of Skopje were below high-water table. It was an opinion of some experts in Skopje, that the heaviest damages from earthquake occurred in places, where the foundation soil was weakened by washing-out of fine sand grains at the decrease of the water after the fload and that the loosening of non-cohesive alluvions caused a bigger compressibility and lower shear strength of the foundation soil at the earthquake, wich occurred 8 months later.

First of all it was necessary to find out, what is the connection between water-level in Vardar and the ground water table in the town. The soil in the nearby environs of the river consists of silt with a rather small permeability. From a big number of boreholes, however, it could be inferred that an old river bed, going through the town is filled by sandy gravel, the permeability of which is very high. This old river bed is connected with the river of today on both ends and, therefore, the lowering of the water in Vardar shall cause a general lowering of the ground-water table in the whole city area, Fig.1.

Soil properties of the coarse grained sandy gravel were investigated by field tests on 2 different sites, one of which was not floaded in 1962 and the second one was floaded at that time. As a suitable vibrator was not available, the elasticity modulae were determined by means of an impact of a hammer on a concrete testing block. In this way vibrations of a shock character were obtained. From the frequency of free vibrations and from the displacement amplitude of the block the elasticity modulus and the damping ratio were calculated. On the vibrogramms, shown in Fig.2., the time of the rebound as well as the time of the impact could also be determined by means of an electric contact. Further, the propagation velocity of elastic waves and the coefficient of absorption were ascertained. The course of the displacement - distance curve shows maxima and minima, referring to a stratified medium. From the tests was concluded that the sandy gravel in the floaded area has a little better quality compared with the unfloaded one. This fact was also prooved by means of dynamic penetration tests. Another in situ test was arranged to proove the possibility of piping. A reservoir enabled to preserve a chosen water-level in a concrete cylinder without bottom, embedded into the unfloaded sandy gravel. The test gave the coefficient of permeability (approx. 1 cms^{-1}) and the gradient at which the washing-out of fine sand grains took place. This gradient was as high as 0.4 and in natural conditions such a high gradient of the water cannot occur, so that a piping at the fload in 1962 is unprobable.

It was, however, necessary to investigate the weak spots in foundation soils. For this reason undisturbed samples of loose, medium grained and of medium dense coarse sand were exposed to vertical and horizontal vibrations on a shaking table. The frequency was changed from 2.5 to 10 cps. and the acceleration from 0.05 to 0.3 g. The results in Fig.3a, 3b show an increase of volume at undrained and a decrease of volume (compaction) at drained tests. The biggest settlement was found at the loose, medium grained sand and represents just for acceleration 0.2 g. approx. 2% of the height. The compaction can reach till 10% from the thickness of a layer and settlements as high as 100 mm are therefore possible at the earthquake. Change of frequency was of a very small influence, except the first step from 2.5 do 3 cps. Fig. 3c. It can be inferred that the seams of fine loose sand are mainly responsible for the heavy destruction of Skopje.

For the smaller area with cohesive foundation soils series of undisturbed samples were also tested on the shaking table. The results are given in Fig.4. From the correlation between the acceleration and the deviatoric shear strength even an increase of the strength with increasing acceleration can be observed. However, the decrease for the shear strength with water saturation is obvious.

Finally it could be concluded, that the lowering of water level in Vardar can bring a small improvement of soil properties in the city area of Skopje. The only exception is the possibility of shrinking of the clayey organic soils but it is limited to a very unimportant part ot the whole place.

Explanation of Figures

Fig.1. Area of Skopje. River Vardar flows along the Tectonic zone of Vardar between the Pelagonesian (Vo) and Serbo-Makedonian (SCG) massive. Ch – old river-channel filled by very permeable alluvions.

Fig.2. Dynamic field tests on a concrete block. a - time scale with oscillographic records of the time-intervals of the impacts (t_1, t_2, t_3) and rebounds (τ_1, τ_2, τ_3). The time of successive impacts are increasing whereas the time of rebounds are decreasing. The course fairly corresponds with the vibrogram of the displacements part - b.

Fig.3. Graphs of the correlation between the acceleration (a/g) and the volume change (%) at the dynamic tests of undisturbed samples of sand on a shaking-table:
a - loose, medium grained sand,
b - medium dense, coarse sand,
c - volume changes (%) in relation to the increase of the frequency. Volume changes:
sw - swelling, se - settlement,
v - vertical vibrations, h - horizontal vibrations.
The samples were water-saturated and either drained (tests No.1, 2, 4 - settlements) or undrained (tests No.3 - swelling).

Fig.4. Dynamic tests of undisturbed samples of clay on a shaking table. Correlation between the deviatoric shear strength ($\sigma_1' - \sigma_3'$) and the acceleration (a) to which the particular samples were submitted.

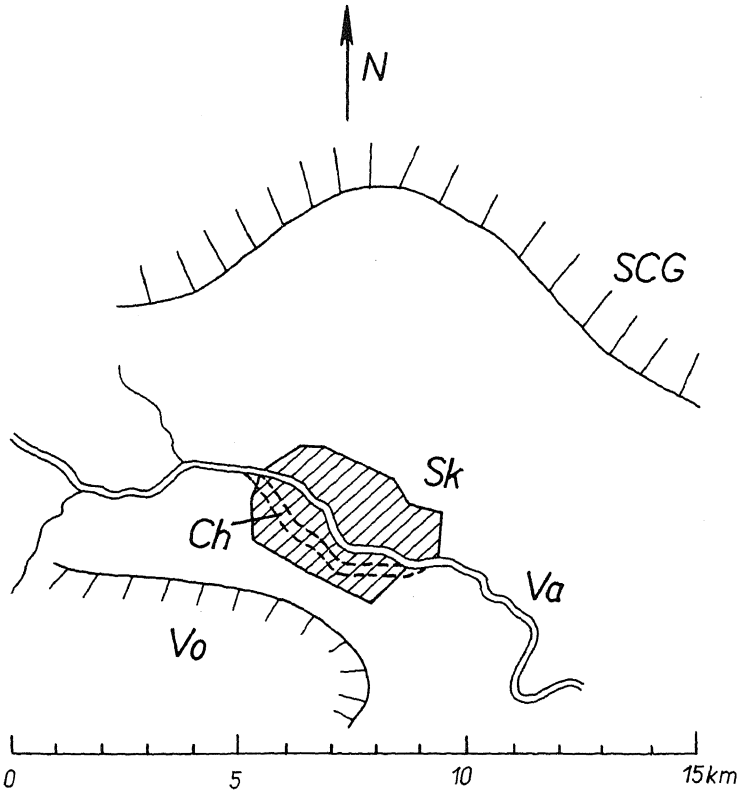

Fig. 1

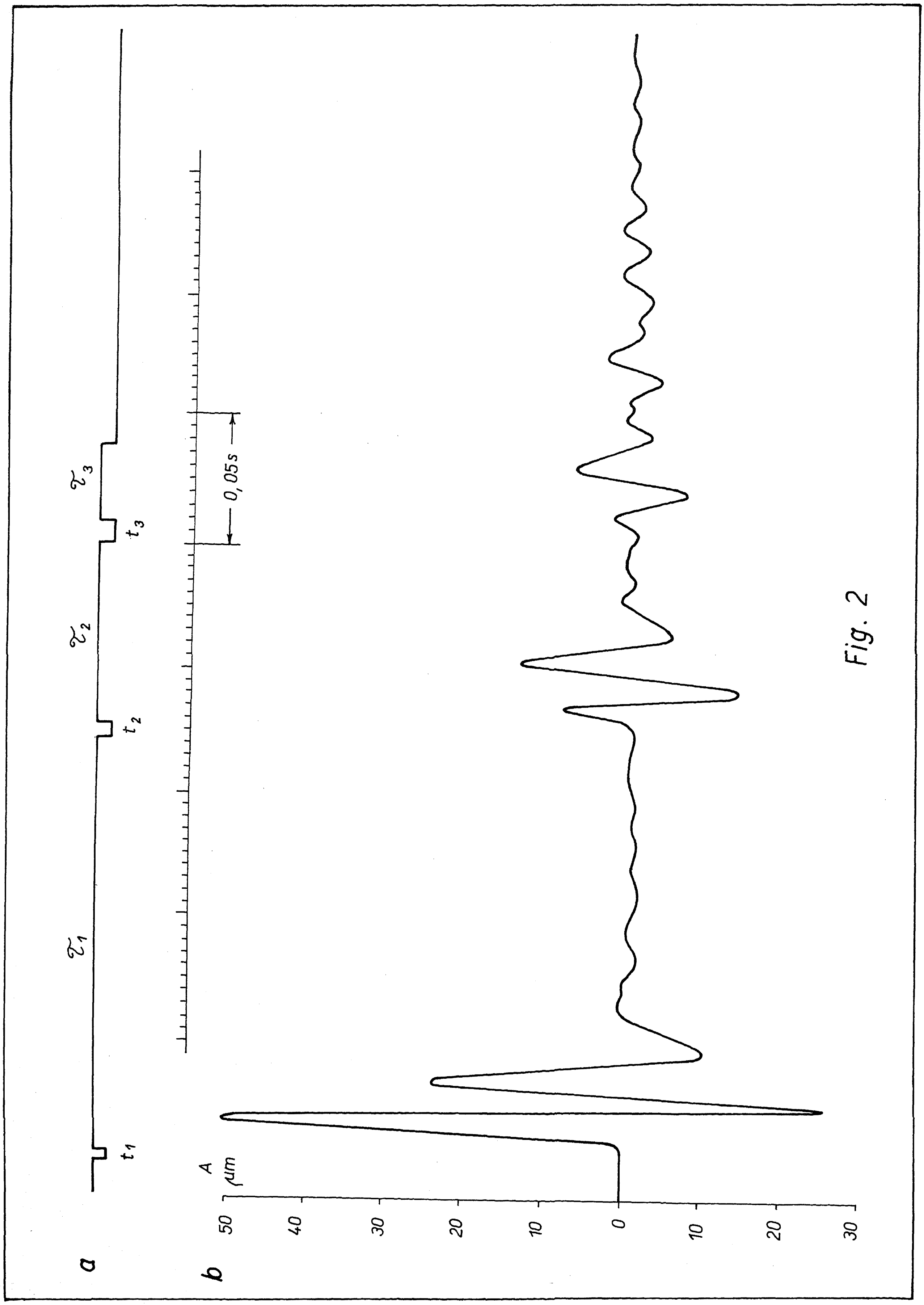

Fig. 2

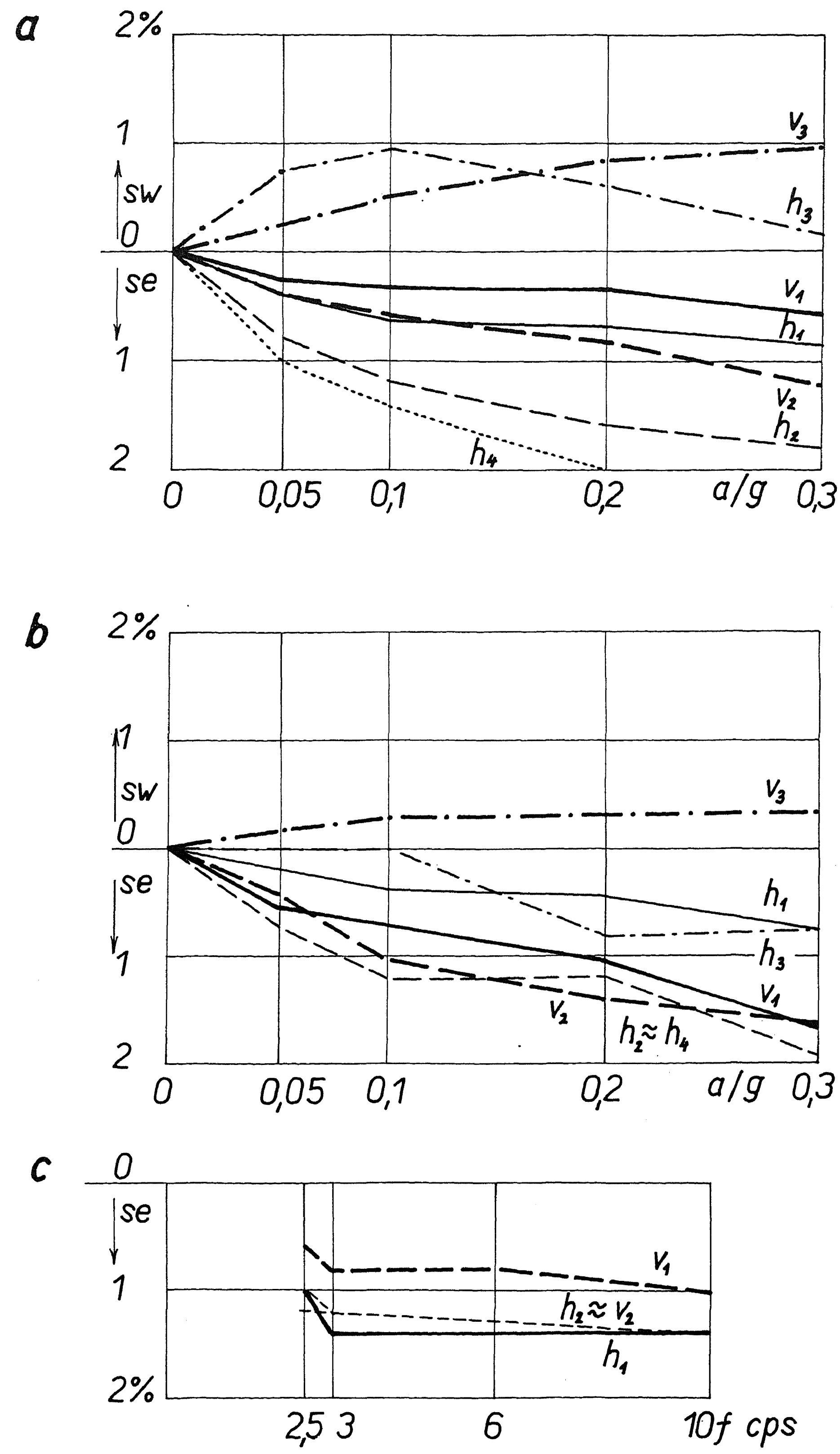
a
2%
1
sw
0
se
1
2
v3
h3
v1
h1
v2
h2
h4
0
0,05
0,1
0,2
a/g
0,3
b
2%
1
sw
0
se
1
2
v3
h1
h3
v1
v2
h2≈h4
0
0,05
0,1
0,2
a/g
0,3
c
0
se
1
2%
v1
h2≈v2
h1
2,5
3
6
10f cps

Fig. 3

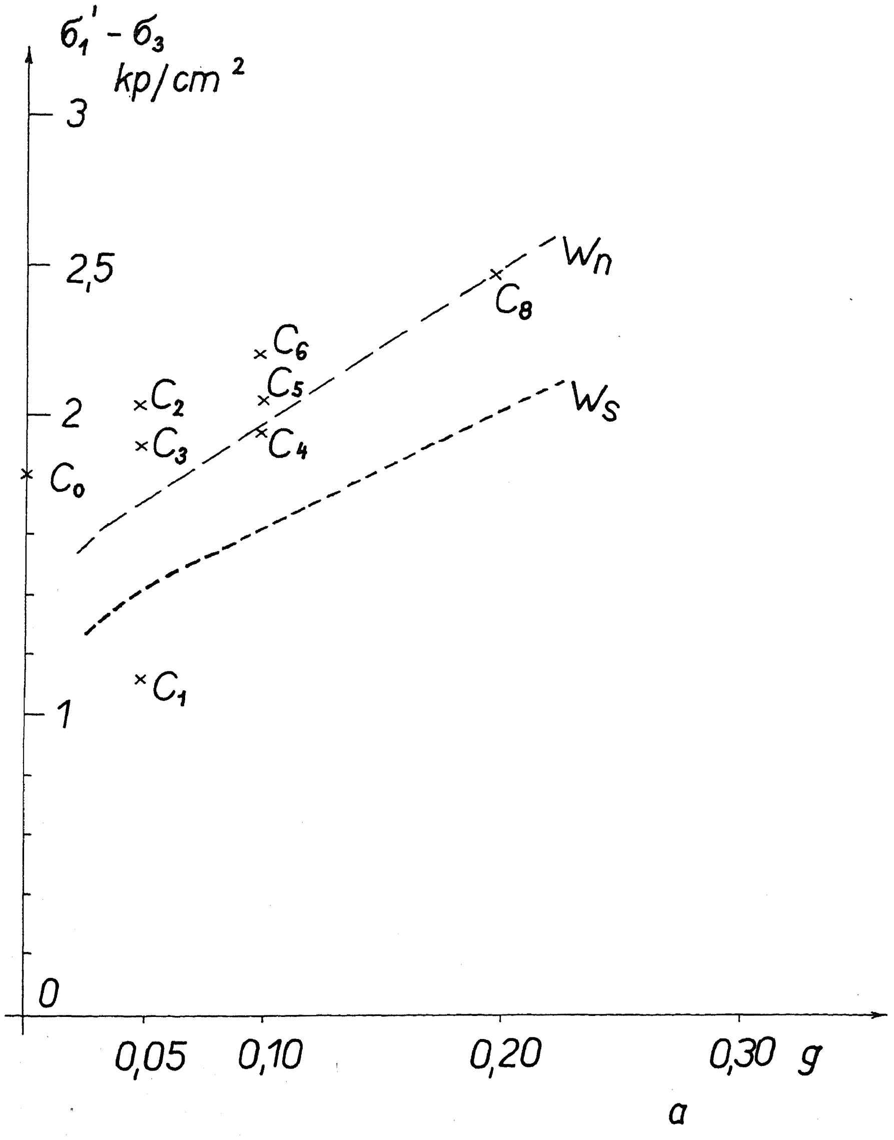

Fig. 4