DAMAGE OF A BUILDING DUE TO WATER LEVEL FLUCTUATIONS IN THE NEARBY RIVER

DOMMAGES A UN BATIMENT EN RAISON DE LA PROXIMITE D'UNE RIVIERE A NIVEAU D'EAU VARIABLE

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SYNOPSIS: Records are available since the ´30s about the movements of the Central building of the Technical University in Budapest. The movements and the magnitude of consequent fissures and cracks have reached a fearful stage in the recent years. Analysis of survey data indicates a local failure during the construction. Completed examination and investigation proved that the origin of the subsequent movements can be traced back partly to the alteration of effective stresses in the soil mass in the wake of water level fluctuations in the river Danube and partly to leaching out of soil grains from the soil in the underground.
From the extrapolation of the settlement curve a time-lag could have been predicted when serious damage endanger the stability of the building.

1 INTRODUCTION

The more than 200 years old Technical University of Budapest was settled to its present location at the beginning of this century. The place, once a flooded area of the Danube, had been regained by help of a regulating dam at the end of the previous century and then refilled with earth, debris, wasted building and earth materials that were removed from the building sites of the capital city. So was built the Central Building of the University (in 1906 - 1909) with a part of it lying on a burried ancient branch of the Danube (Fig.1).

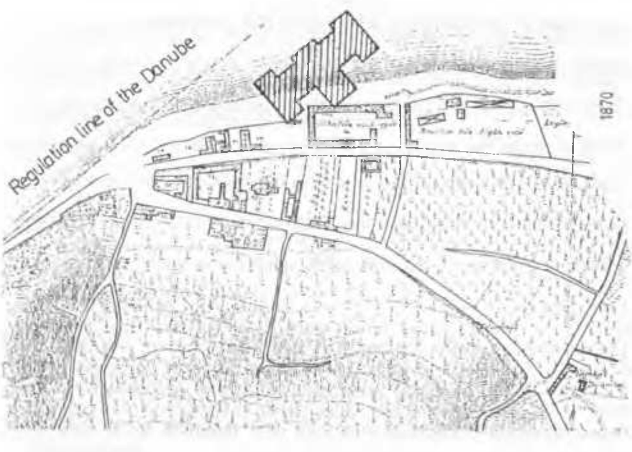

Fig. 1 Ancient map of 1870 with layout of the building

About the malignant movements of the building, records go back to the early ´30s ; also the esteemed professor Jáky was involved in those investigations. Building movements and consecutively arising fissures and cracks have, however, attained a fearfull degree in the recent years, so it became unevitable to conduct an intensive investigation into the case.

2 BACKGROUND DATA

The voluminous building of 200 m length and partly 50 m, partly 110 m widths consists of the northern, the middle and the southern connecting wings between them. At the turret-like ending of each block, pertaining cross walls and pertinent board wall sections have evidently contributed to an enhanced rigidity of the building in comparison of thereof.
Walls of the building complex consist of tiles and the foundations were made of concrete strips. Foundation level lies on the top of the naturally deposited gravelly sediment of the Danube, at about 7 m depths below the ground surface. Several exploration pits revealed - surprisingly - that the width of strip foundations were consequently narrover below the more heavily loaded connecting walls than below the main edge walls.

The foundation system with pertinent loads in the building is shown in Fig 2. In the view of present design practice the remark has to be raised that foundation stresses achieved extremely high values (σ_{max} ≈ 950 kN/m²), which were not allowed today under even more advantageous soil conditions.

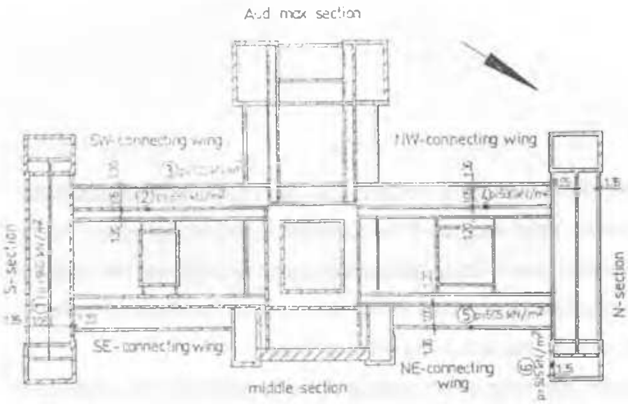

Fig 2 Foundation system of the building

3 DAMAGE PATTERNS

Predominantly the southern block section, even more expressively its mid section between the two turrets and the SE connecting wing were effected by damage. The pattern of cracks on the southern face of the building (Fig. 3) refers to reasons of subground origin.

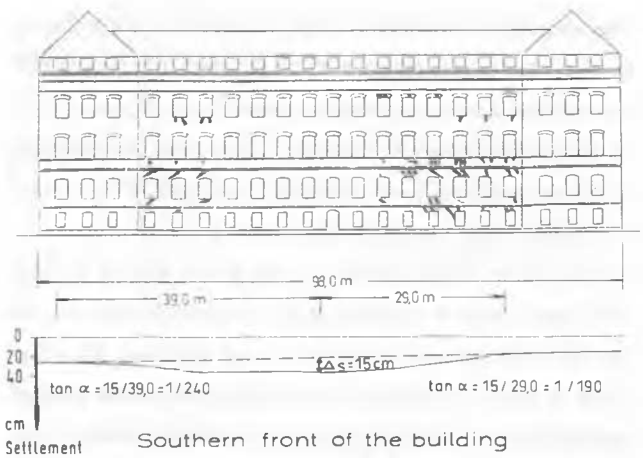

Fig. 3 Pattern of cracks on the southern front

4 LEVELLING DATA

The staff of the Surveying Institute carried out systematic surveys about the movements of the building in the past 70 years. The results are available in respect of ensued differential settlements in the various periods, it is - however - not possible to establish from these data, what was the amount of total settlements of the building in the past. Measured results were not evaluated comprehensively.

The wall footing was originally surely designed will horizontal lines, its elevation has been levelled in 1991. The isohypses deduced from the general survey, are presented in Fig. 4.

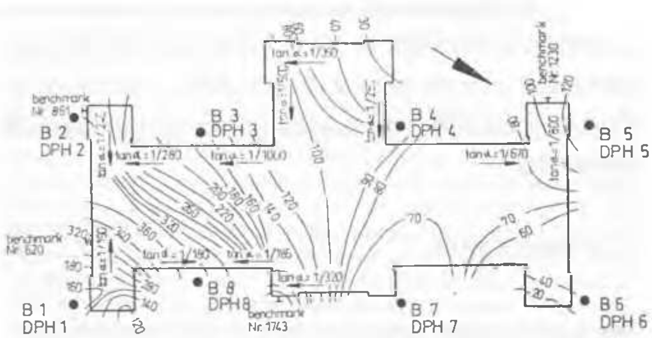

Fig. 4 Levelling data

The contour lines show a plain view about ensued settlements. In the southern building block and in the SE connecting wing total settlements amounted to 36 cm.

Exactly similar results were obtained from the levelling of the first and second floor passageways. Differential settlements of 290 mm and 195 mm were measured on the first and the second floor, respectively.

Analysis of settlements infers that the movements started already during the time of construction: signs of trying to rectify their influence can be traced at various elevations in the building. It might be supposed that approximately 7 cm settlement had developed when the building height reached up to elevation of the first floor and an additional 9 cm, i.e. all together 16 cm settlement, by the time when the second floor was completed.

Bench marks were inserted in the form of pins into the wall footings of the building at various stage of settlement. These were levelled in regular intervals and records were duly kept till today.

Time dependent settlement of the benchmarks is shown in Fig.5. Principle of this evaluation was, that measured settlements were plotted backwards in time, starting from the present elevation of the wall footing, known from most recent levelling results.

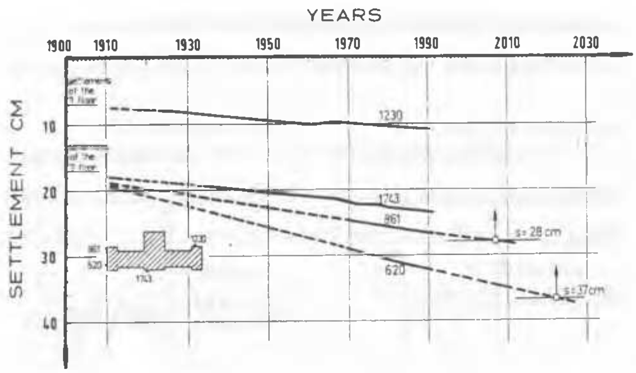

Fig. 5 Time dipendent settlement of the bench marks

The following conclusion can be reached from this figure:

- the northern part of the building suffered less displacement than the southern part of it and even more settlement took place in the front wall to the Danube;
- the character of settlement appears to be linear and not that of a conventional consolidation curve;
- the tendency in the settlement of bench mark No 1743 shows an abrupt increase after 1967: this fact might be accounted for the influence of increased loads arosen by the reconstruction work in the roof space above the SE connecting section in 1963-64.

For numerical identification of wall movements, the relative angle of deflection is used. Values of tanα = 1 / 180 to 240 can be calculated for the mostly perilled front section of the building on the southern and south-eastern side. Values of other building sections can be read in Fig. 4.

5 RESULTS OF SOIL EXPLORATIONS

Large diameter drilling holes and heavy dynamic probings (DPH) were conducted to reveal soil conditions in the underground. Findings met a rather uniform stratification in the underground.

A vast, man-made fill of various composition can be detected all around below the surface. A black, organic silt follows which is underlain by the gravelly deposit of the Danube. Thereafter comes the basic Kiscelli clay at 13 to 15 m depth below ground level on the western side and at approximately 18 m depth on the eastern side.

Results of heavy dynamic probings show significant differences in the density of the sandy gravel below the southern and nourthern parts of the building. In the southern part resistance of n_{20} = 8 to 15 has been experienced, showing a rather loose conditionn in the average. On the northern part values of n_{20} = 30, or greater were achieved i.e. the sandy gravel was in a dense to very dense condition at these places.

Fig. 6 is intended to inform about characteristic probing results below the southern and northern sections of the building.

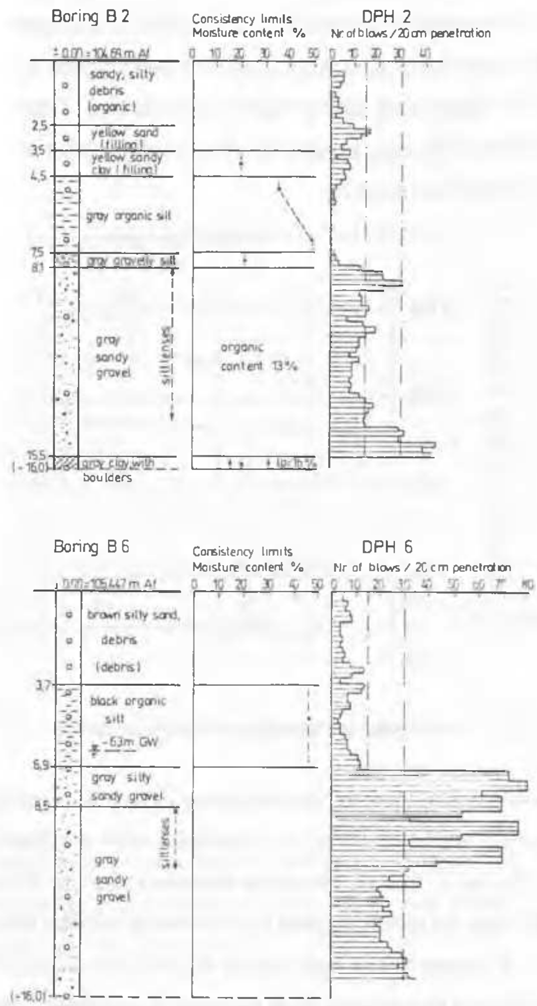

Fig. 6 Typical soil profiles and sounding results

6 SETTLEMENT ANALYSIS

With respect to the interference of closely arranged foundations and the superpositionof arising stresses, each building section has been assumed in the calculation as an extended slab with uniformly distributed load. Considering an irrationally low value for the modulus of compressibility of a sandy gravel (E_s = 20 MN/m^2), the calculated total settlement would come to only s = 10 cm, which is only one third of the actual one. Therefore the influence of other reason or effect had to be found to explain this discrepancy.

7 ANALYSIS OF THE LOAD BEARING CAPACITY OF FOUNDATION

The load bearing capacity of foundation was checked on the basis of Therzaghi´s soil failure theory. Since the foundations lie deep below the ground surface and the sandy gravel is loose the so called local failure might be anticipated. Terzaghi suggested for this case to take only the two third value of the internal friction into account.

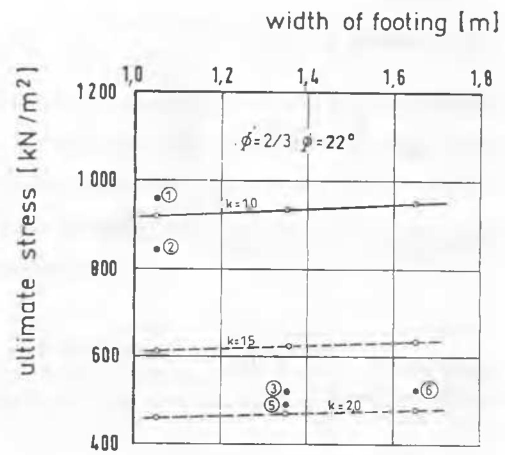

Fig. 7 Load bearing capacity and factor of safety

The stresses belonging to different safety factors (k=1 means the ultimate bearing capacity) vs. foundation width are illustrated on the Fig. 7. Plotting the actual stresses (dots 1 to 5) can be seen, that the factor of safety for the internal wall lies about k = 1,0. It means that a local failure might occur during the construction of the building. Most probably, it manifested itself in a sudden, subsidence- or collapsing-like settlement

8 EFFECT OF WATER LEVEL FLUCTUATION IN THE DANUBE

8.1 Effect of repeated loading

Fluctuation of ground-water level induces significant changes in activated effective stresse in the soil. Repeated subsequent increase and decrease of stresses cause additional compression in the ganular soil skeleton (Fig. 8).

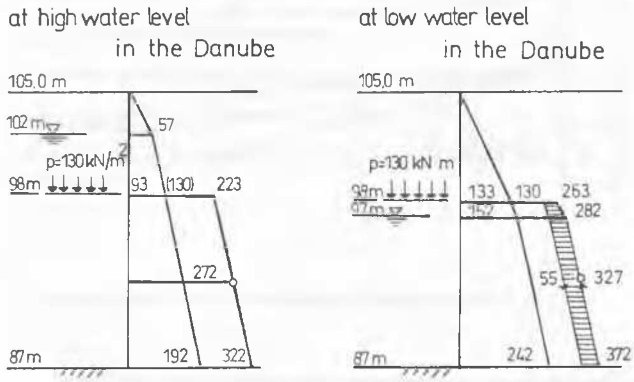

Fig. 8 Stress diagramms at high and low water level

A model test has been completed to clarify this phenomenon. Arrangament of the testing procedure and the results are shown in Fig. 9. Alterating loads in the range of pressures caused by the dead weight, the live weight from the building

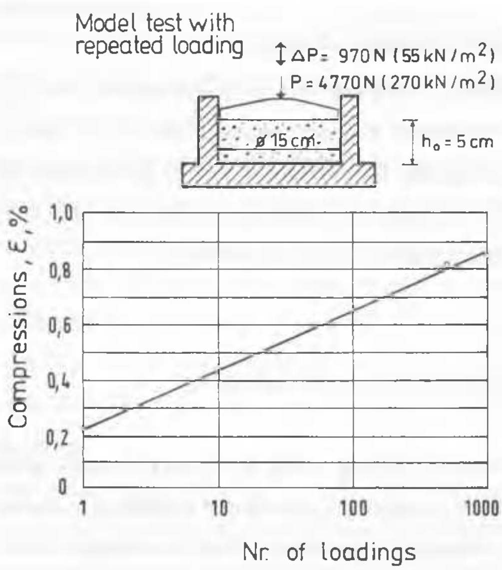

Fig.9 Arrangement of model test and test results

and the stress due to fluctuation of the water level in the Danube were sequentially imposed on the soil specimen.

The test has proved that with increasing number of repeated loads (i. e. cycles of flood) compression is continuosly progressing, though in a diminutive rate (logarithmic scale).

8.1 Effect of leaching

It has been examined, how far the composition of the granular subsoil material is exposed to the influence of the percolating ground-water: might some grains washed away?

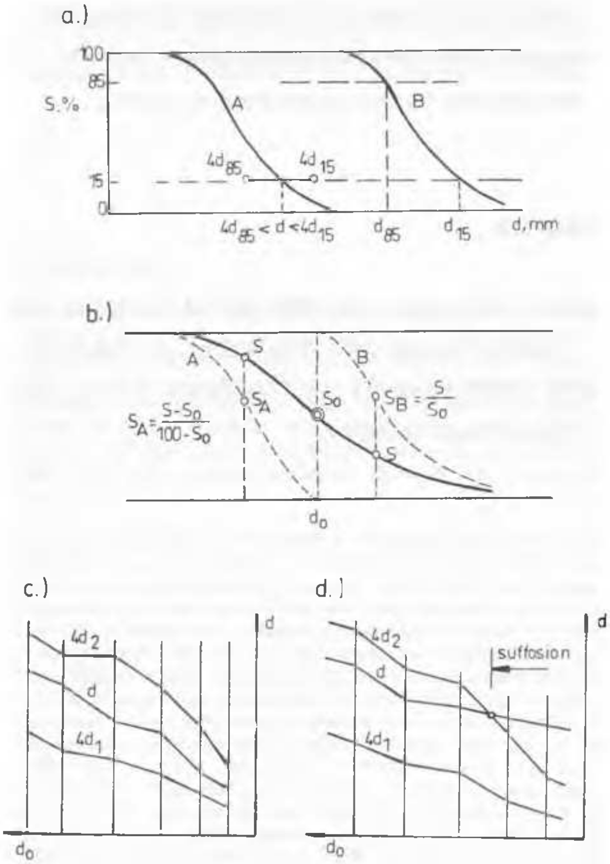

Fig. 10 Examination of self - filtering capacity

Thezaghi's filtering rule was used (Fig. 10a). When the self-filtering capacity of a soil is examined, the soil is divided in two portions at any arbitrary grain size, d_0 (respectively soils A and B, Fig. 10b). It has to be checked whether part A would satisfy the filtering rule against part B. The procedure is than to be repeated for several d_0 grain sizes. Plotting the results in a d_0 - d coordinate system, it can also be read off whether the soil was capable for self-filtering (Fig. 10c) or not, respectively which grain sizes are prone for being leached out (Fig. 10d). Fig. 11 shows an example about a completed tests. On the Fig. 12 the range of tested soil is illustrated.

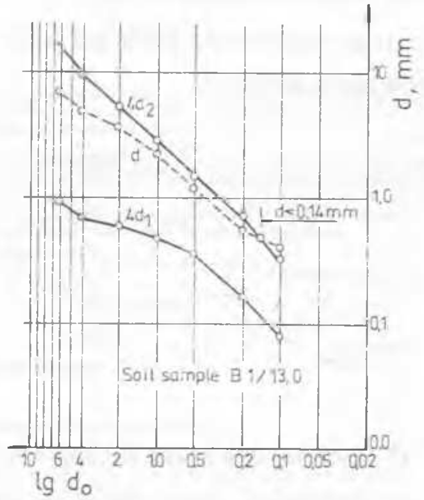

Fig.11 Result of an investigation

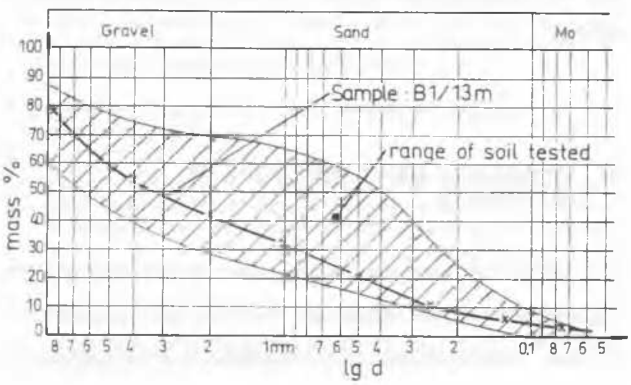

Fig.12 Range of soils tested

Our tests have proven that the sandy gravel has no self-filtering capacity and potencially agout 20 per cent of the grains might be washed out from it.

9 FORECAST OF PRESUMABLE SETTLEMENTS

Records from the longlasting observation period enable a prediction about the future performance of the building. In Fig. 13 the deformation line of the wall footing of the building´s southern front is presented. Calculations show that the critical angle of deflection ($\tan\alpha = 1/150$) will be reached at a settlement of s = 19 cm. The corresponding deformation line can be constructed and from that curve the anticipated settlement of the bench marks can be predected.

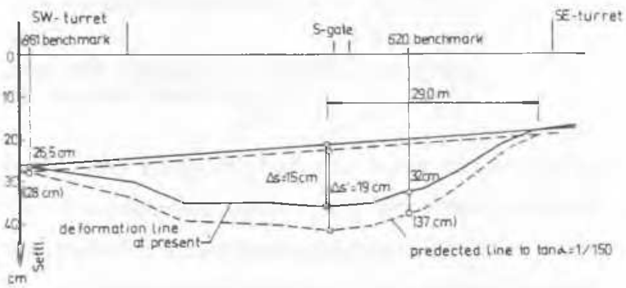

Fig. 13 Predected deformation line to $\tan\alpha = 1/150$

From the extrapolated deformation curve in Fig. 5 the expected time for such settlements of the bench marks can be anticipated.

10 CONCLUSION ABOUT THE CAUSES OF MOVEMENTS

Our performed examinations revealed that damage in the southern part of the building can be attributed to subsoil conditions. Predominant part of the movements developed during and soon after the construction of the building. Loose subsoil and the relatively exaggerated soil stress induced a local soil failure below the foundation.

Subsequent movements of the building projected a linear trend and the same phenomenon is still in process. Completed examination and investigation have proved that the reason for this nuissance originates in the fluctuation of the water level in the nearby Danube, which - on the other hand - influences directly the movement of the ground water level.

Frequent ground-water level fluctuation induces repeated changes of the effective stresses in the soil mass. All the time, this fact evolves an additional compression of the soil below the foundations.

Further on, the frequent change of the ground-water level produces an alteration in the flow pressure and exercises a pumping effect through which a portion of the grains will be washed away.

To stop the continuity of the settlement the loose sandy gravel has to be neutrelized. Loads should be transferred to the underlying load bearing strata by means of:

- underpinnig the walls by small diameter injected piles
- supporting the wall foundations by "jet-grouting"
- strengthening the loose sandy gravel by grouting.

REFERENCES

Terzaghi, K. and Peck, R.B. (1967). Soil Mechanics in Engineering Practices. John Wiley & Sons, Inc., New York

Kézdi, Á. (1980). Handbook of soil Mechanics. Vol. 1-4. Akadémiai Kiadó, Budapest