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REASONING ABOUT THE DAMAGE IN THE CENTRAL BUILDING OF THE TECHNICAL UNIVERSITY OF BUDAPEST

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Abstract

Since the 30s records are available about the movements of the Central Building of the Technical University of Budapest. The movements and the magnitude of consequent 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.

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 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 from 1906 to 1909 with a part of it lying on an ancient branch of the Danube (*Fig. 1*).

Fig. 2 shows the refilled land at a later stage of construction works.

Honoured by its determinant location in the general view of the city, by its eminent academic role and by its architectural appearance, the building has been declared as a protected monument.

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 fearful degree in the recent years, so it became unevitable to conduct an intensive investigation into the case.

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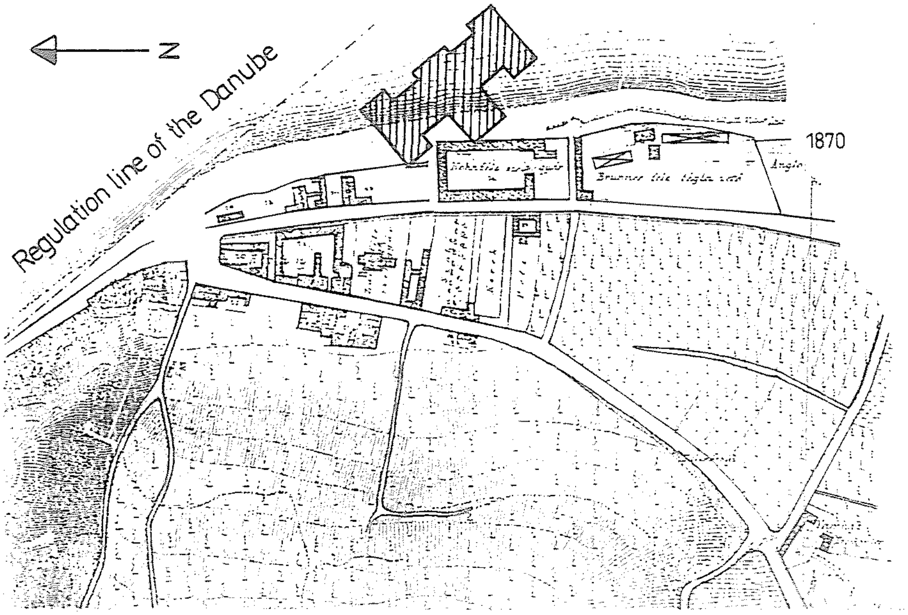

Fig. 1. Ancient map of 1870 with layout of the building

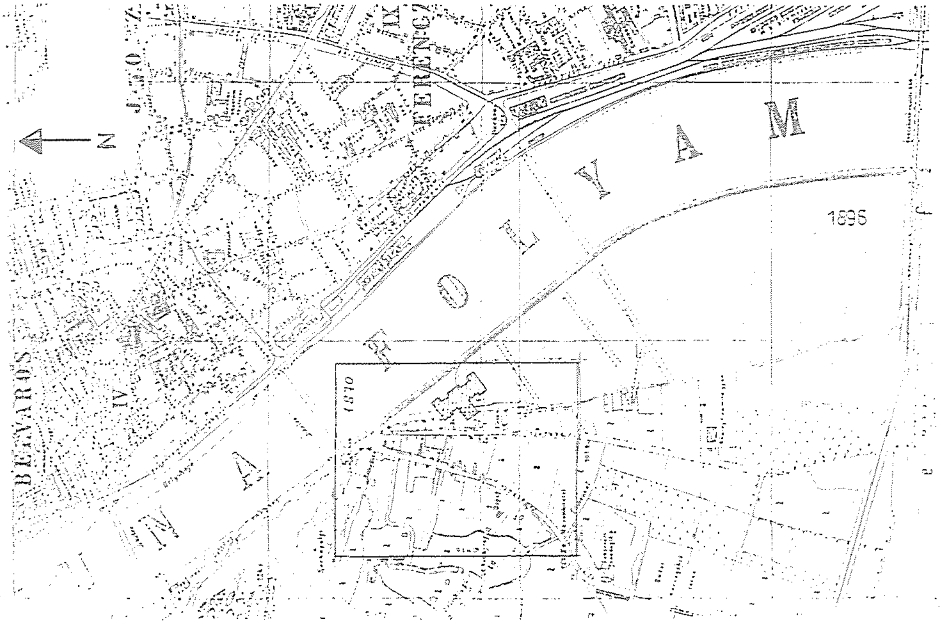

Fig. 2. An ancient map of 1896 with layout of the building

2. Background Data

The voluminous building of 200 m length and partly 50 m, partly 110 m widths consists of the northern, middle and southern blocks and the northern and 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 that.

Accountable reconstruction works in the building occurred in three occasions:

- in the early '20 s, when a 1000 ton and a second 500 ton massive concrete blocks had been erected in the north-western block of the building. It served for establishing a fix base for surveying monument and a calibration bench in the Surveying Institute;
- 1941–43 an additional storey was erected over the southern building block, the SE and the SW connecting wings and the Auditorium Maximum Block;
- in 1963–64 the roof space above the SE connecting wing was built in for utilisation.

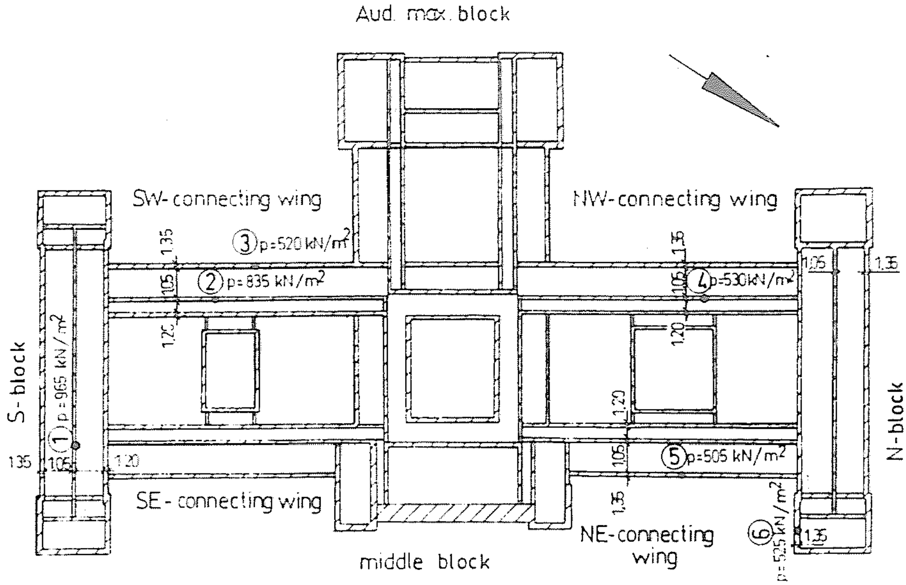

Fig. 3. Foundation system of the building

Walls of the building complex consist of bricks 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 narrower below the more heavily loaded middle walls than below the main edge walls.

The foundation system with pertinent loads in the building is shown in *Fig. 3.* In the view of the present design practice the remark has to be raised that foundation stresses achieved extremely high values ($\sigma_{\max} \approx 950\,\mathrm{kN/m^2}$) which were not allowed today under even more advantageous soil conditions.

3. Damage Patterns

Predominantly the southern block, even more expressively its mid section between the two turrets and the SE connecting wing were affected by damage. The pattern of cracks on the southern face of the building refers to reasons of subground origin (*Fig. 4*).

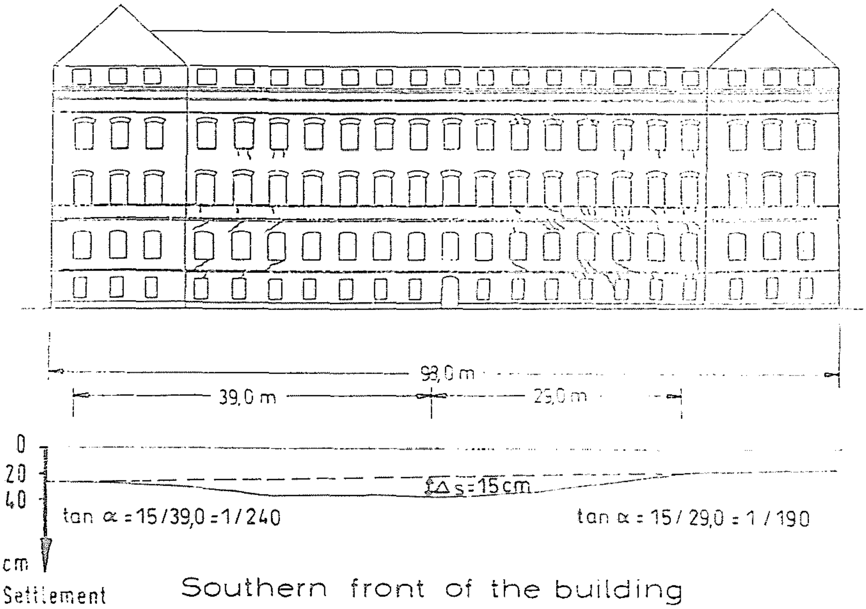

Fig. 4. Pattern of cracks on the southern front

4. Investigations Carried out by Professors Oltay and Jáky

In the early '20 s the Surveying Institute established huge foundation blocks in the inside of the building into which controlling bench marks were incorporated. Levelling of these bench marks was carried out with accuracy of first order for over 10 years.

Conclusion of these measurements implies that:

- the foundation block heaved or sunk always parallelly with the alteration of the buoying force provoked by the fluctuation of water level in the Danube. Magnitude of this movement attained e.g. 1.1 mm for a 4.5 m change of the water level;
- both the foundation block and the sorrounding edge walls suffered a continuous settlement of about 0.5 mm to 0.6 mm in every year;
- the fluctuation of the ground-water level followed regularly and without a time lapse the change of water level in the Danube.

Professor Oltay used to say: 'The Danube flows not only in its bed, but also under the ground surface, to some significant distance from the river banks.'

Professor Jáky completed an investigation about the compressibility of the silty strata below the concrete block in the Surveying Institute in 1933(!). Alternating loading effects were imposed on the specimen, imitating the variation of heaving forces in the wake of water level fluctuations.

Reprints of the original investigations are presented in *Fig. 5* and *Fig. 6*.

5. 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 various periods. From these data, it is however, not possible to establish what was the amount of total settlements of the building in the past. Measured results were not evaluated comprehensively.

It can surely be assumed that the wall footing was originally designed with horizontal lines. Its elevation was levelled in 1991. The isohypses deduced from the general survey are presented in *Fig. 7*.

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

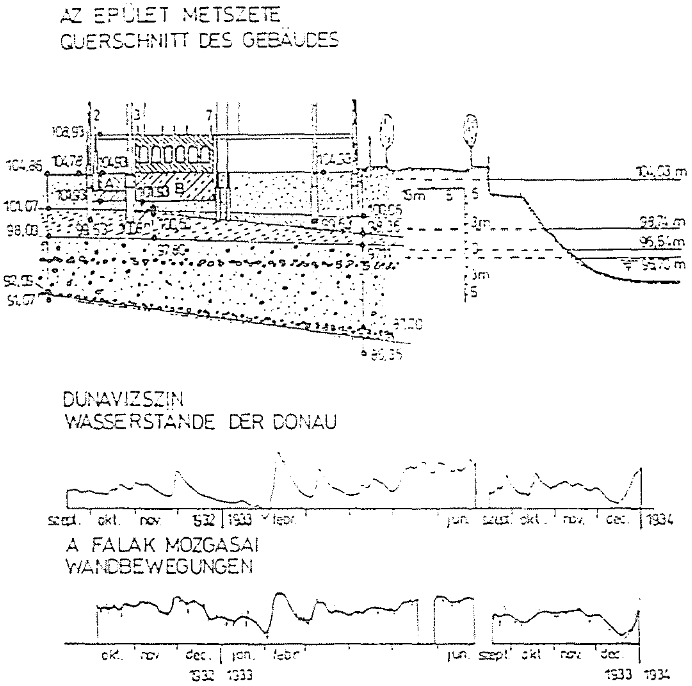

Fig. 5. Some results of professor Oltai

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. altogether 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 stages 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. 8.* 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.

The following conclusions can be drawn from this figure:

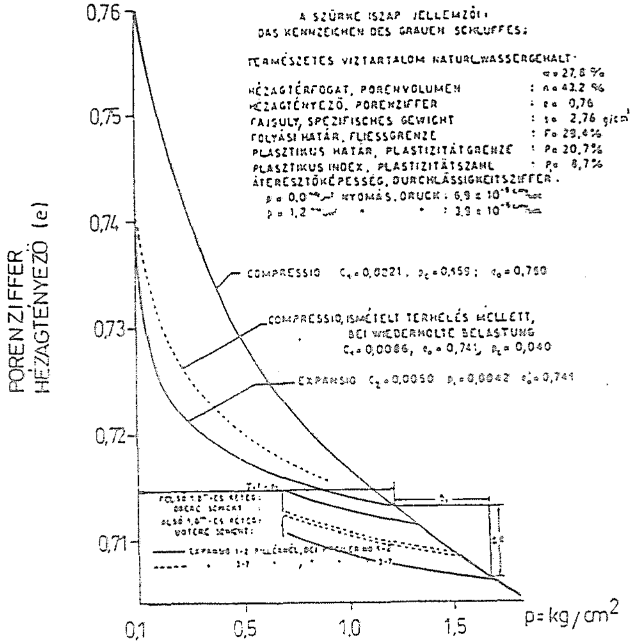

Fig. 6. Compression of a silt sample (from professor Jáki, 1933)

- 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 benchmark No 1743 shows an abrupt increase after 1967; this fact might be accounted for the influence of increased loads arisen by the reconstruction work in the roof space in 1963–64.

For numerical identification of wall movements the relative angle of deflection is used.

Values of $\tan\alpha = 1/180$ 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. 5.*

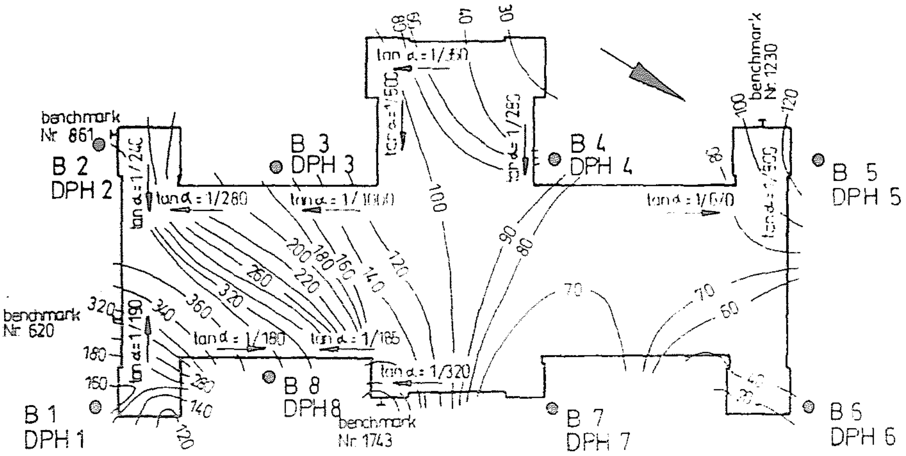

Fig. 7. Levelling data

6. Results of Soil Explorations

Large diameter drillings (B) 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 northern parts of the building. In the southern part resistance of $n_{20} = 8$ to 15 has been experienced, showing a rather loose condition 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. 9 is intended to inform about characteristic probing results below the southern and northern sections of the building.

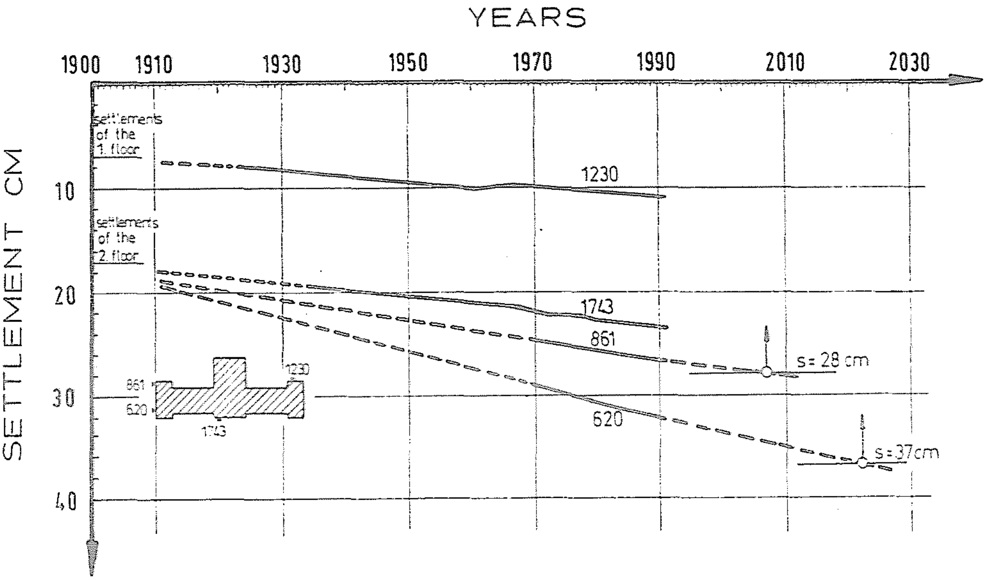

Fig. 8. Time dependent settlement of the benchmarks

7. Settlement Analysis

With respect to the interference of closely arranged foundations and the superposition of 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 ($E_s = 20\,\mathrm{MN/m^2}$), 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.

8. 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 (in our case: $2/3\varphi = 2/3 \cdot 33 = 22°$).

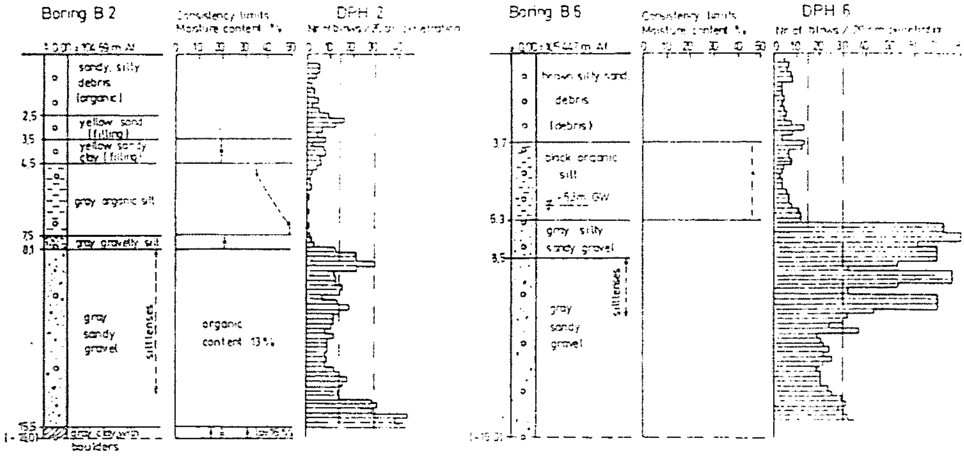

Fig. 9. Typical soil profiles and sounding results

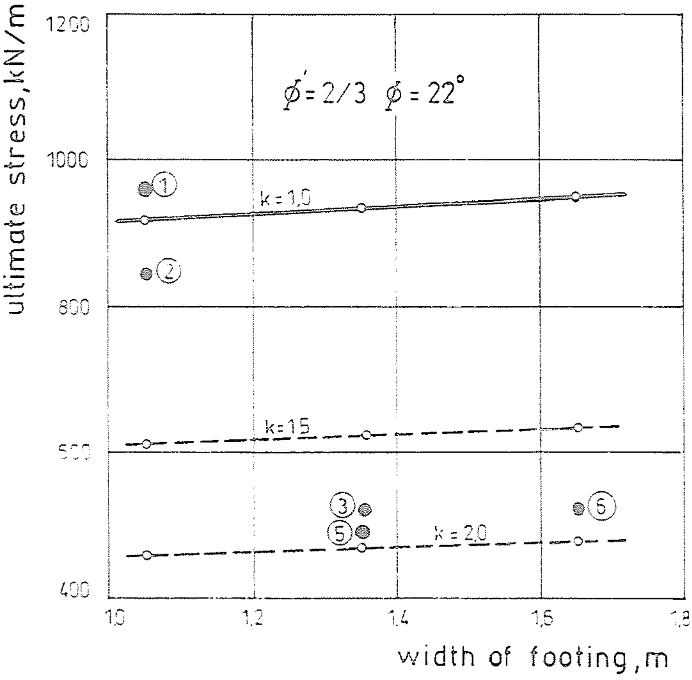

Fig. 10. Load bearing capacity and factor of safety

The stresses belonging to different safety factors (e.g. $k = 1$ means the ultimate bearing capacity) vs. foundation width are illustrated on the *Fig. 10.* Plotting the actual stresses according to *Fig. 3* (dots 1 to 6) can be seen that the factor of safety for the internal walls 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.

9. Effect of Water Level Fluctuation in the Danube

9.1. Effect of Repeated Loading

Fluctuation of ground-water level induces significant changes in effective stresses in the soil. Repeated subsequent increase and decrease of stresses cause additional compression in the granular soil skeleton (*Fig. 11*).

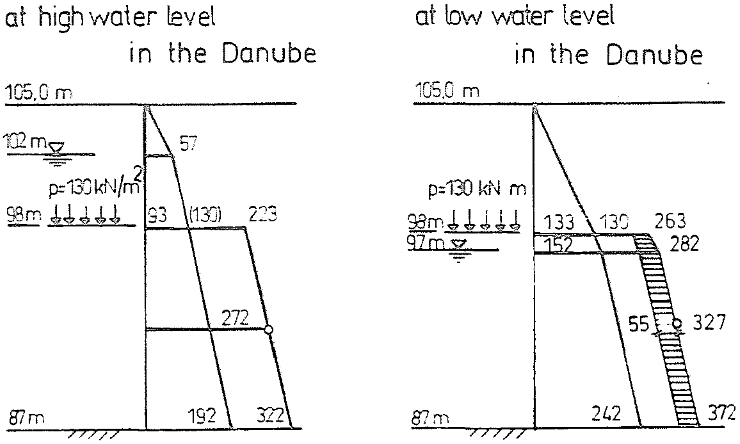

Fig. 11. Stress diagrams at high and low water level

A model test has been completed to clarify this phenomenon. Arrangement of the testing procedure and the results are shown in *Fig. 12.* Alternating loads in the range of pressures caused by the dead weight, the

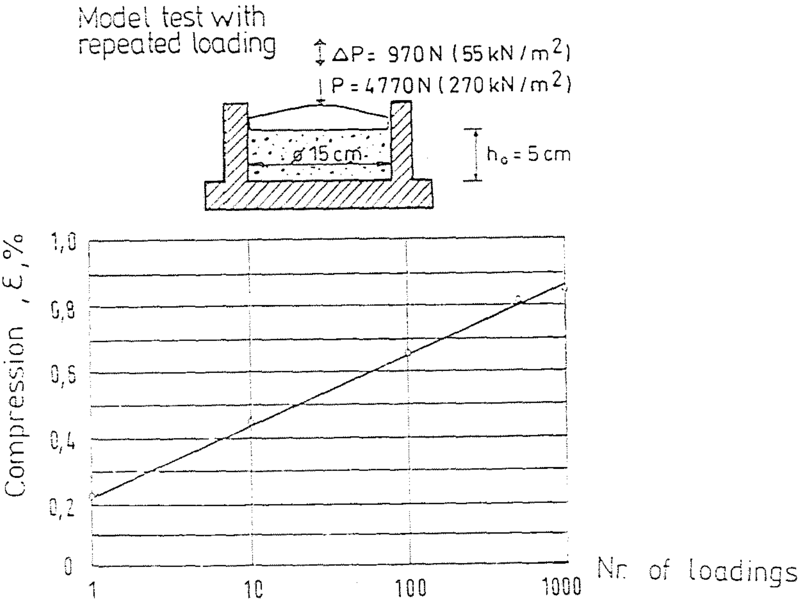

Fig. 12. Arrangement of model test and test result

live weight from the building 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 continuously progressing, though in a diminutive rate (logarithmic scale).

9.2. 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 be washed away and if so, to which extent?

Thezagh's filtering rule will be used. When the self-filtering capacity of a soil is examined, the soil is divided into two portions at any arbitrary grain size, d_0 (respectively soils A and B, *Fig. 13a*). It has to be checked whether part A would satisfy the filtering rule against part B (*Fig. 13b*). The procedure is then 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. 13c*) or not, respectively which grain sizes are prone to being leached out (*Fig. 13d*).

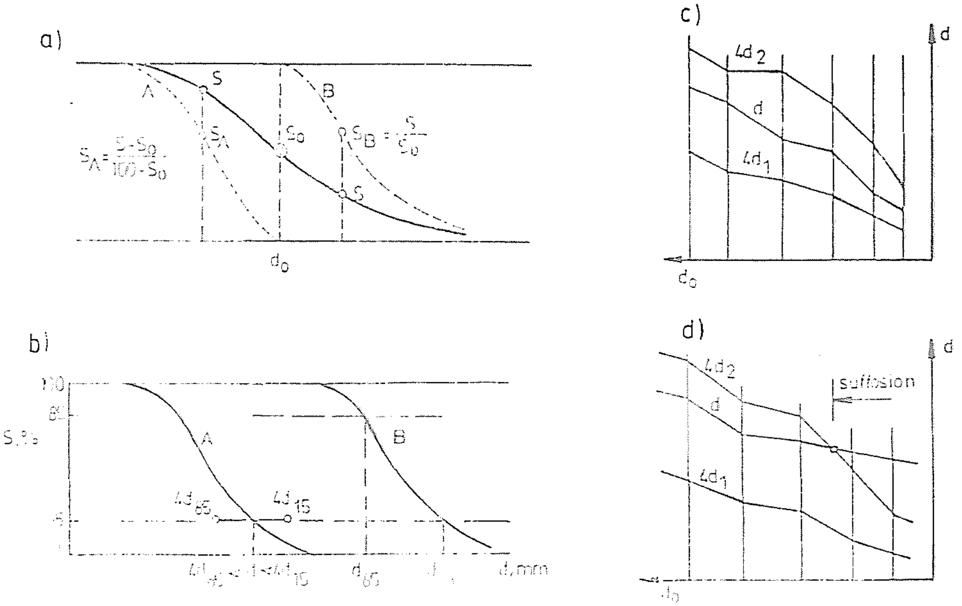

Fig. 13. Examination of self-filtering capacity

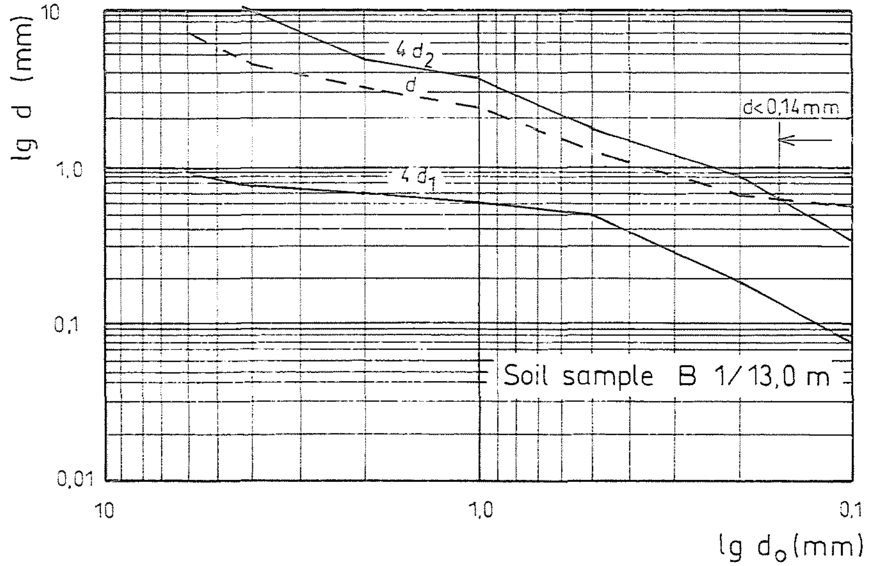

Fig. 14. Result of an investigation

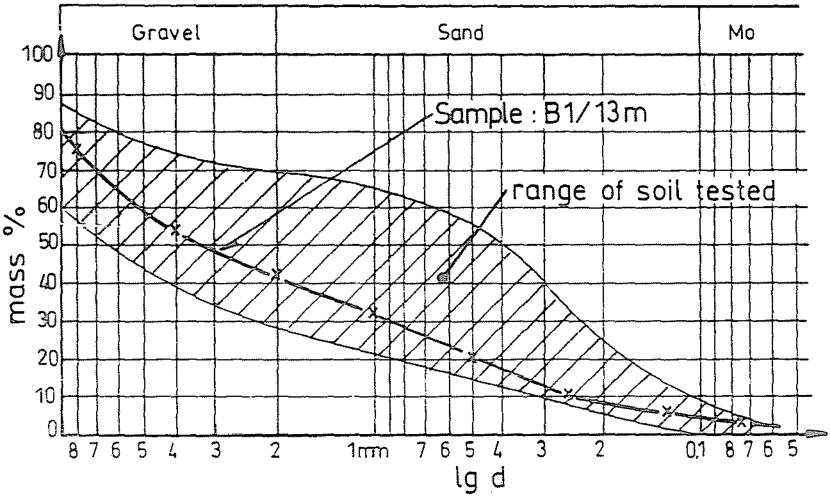

Fig. 15. Range of soils tested

Fig. 14 shows an example about a completed test. On the *Fig. 15* the range of tested soils is illustrated.

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

10. Forecast of Presumable Settlements

Records from the longlasting observation period enable a prediction about the future performance of the building. In *Fig. 16* the deformation line of the wall footing of the building's southern front is presented. Calculations show that the critical angular distortion ($\tan \alpha = 1/150$) 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 predicted. The expected time for such settlement can be read off from the extrapolated deformation line in *Fig. 8* — the southern part of the building may get into critical situation in 25 to 30 years.

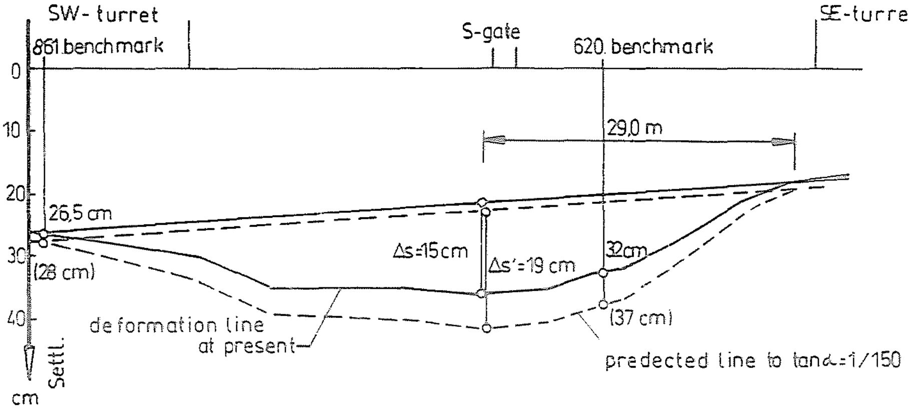

Fig. 16. Predicted deformation line to $\tan \alpha = 1/150$

11. Conclusion about the Causes of Movements

Our 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 phenomenon is still in process. Completed examination and investigation have proved that the reason for this nuisance 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 excluded from the bearing capacity. Loads should be transferred to the underlying load bearing strata e.g. by means of:

- underpinning the walls by small diameter injected piles
- underpinning the wall foundations by 'jet-grouting'
- strengthening the loose sandy gravel by grouting.

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