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DETECTION OF VERTICAL DEFORMATIONS OF A LARGE BUILDING

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Abstract

The great central building of Technical University of Budapest was built during the years 1902 – 1909 mostly over the filled river bed of the Danube.

The building has suffered heavy vertical deformation since then. Hence it became necessary to detect the exact amount and time course of deformation by an investigational survey.

Firstly the uneven subsidences of loaded outer walls, which were resulted up to the present, were detected such, that the height of one rim passing completely around, — and was planned originally to be horizontal — was measured. Its deviations from horizontal plane practically equal to the uneven subsidences of outer walls (*Figs. 1* and *2*).

We gained data for the uneven subsidences of the inner parts of building by analyzing previous repeated levellings taken to the axes of inner passages (*Fig. 3*).

The overall subsidence of building was detected by using such results of levelling of first-order benchmarks placed previously in the basement of building, which were connected time by time with outer first-order benchmarks that can be taken as motionless (*Fig. 5* and *Tables*).

We have located critical sites of deformation and ascertained that the subsidence and uneven subsidence of the building is going on at present as well.

Some new first-order benchmarks were established along the loaded outer walls and inside the building. Hence accurate data can be gained in the future for short periods of time (e.g. one year) for the relative and absolute movements of the building.

Keywords: deformation of building, uneven subsidence, deformation measurement by first-order levelling.

The central building of the Technical University of Budapest which is 200 m long and 110 m wide was built from 1902 to 1909 next to the river Danube. Essentially, the building is combined by three parts (northern, southern and central) connected by two (western and eastern) wings. The foundation system of the building is strip foundation.

It became clear especially of late decades that certain parts of the building in the course of time underwent different but very significant vertical deformation (irregular subsidence). Therefore a deformation measurement became necessary which would reveal the process of vertical deformation without delay and with the required accuracy.

We have expected from this survey to furnish important initial information to localize critical points of the building, to recognize the factors producing the movement and then to make plans to stop the movement (stabilize the building).

The speciality of the deformation measurement has arisen from the fact that on one hand the basis of certain assumptions and on the other hand the data of height measurements which were carried out at different parts of the building at separate moments of time on different purposes and accuracy had to be used to develop both absolute and relative picture of movement of the whole building.

The vertical deformations of the building, could be determined by two methods:

a) Assuming that certain parts of the building (the rims, walking levels, etc.), planned to be horizontal were really levelled correctly, by measuring the present state of deviations from the horizontal plane theoretically corresponds to an uneven subsidence.
b) The results of previous and present measurements taken to certain first order bench-marks — placed inside the building for different reasons — could also be compared.

We have used both of these methods during the investigation process.

Detection of Deformations on the Basis of Dislocation of Horizontal Elements

We have chosen a certain rim of the building, which passes around and was planned to be horizontal, and we levelled 236 points of it with several mm accuracy. On the basis of the resulting height differences we plotted on the sketch of the building drawn to scale the isolines of the surface spanned by the present positions of these rim points (*Fig. 1*). It resulted from the levelling of the footing that the most highly elevated point is the NE corner of the building, so we chose this point to be the relative zero for the isolines. It is possible, of course, that this point subsided as well, but it can be stated with great reliability that this could be of a very small extent. The basis of this statement is the fact that dynamic probing took place round the building (BICZÓK, 1991), and it made clear that the sandy gravel which forms the underlying soil of the building, here, in contrast to all the other sites of probing, is of a very compact state. The irregular

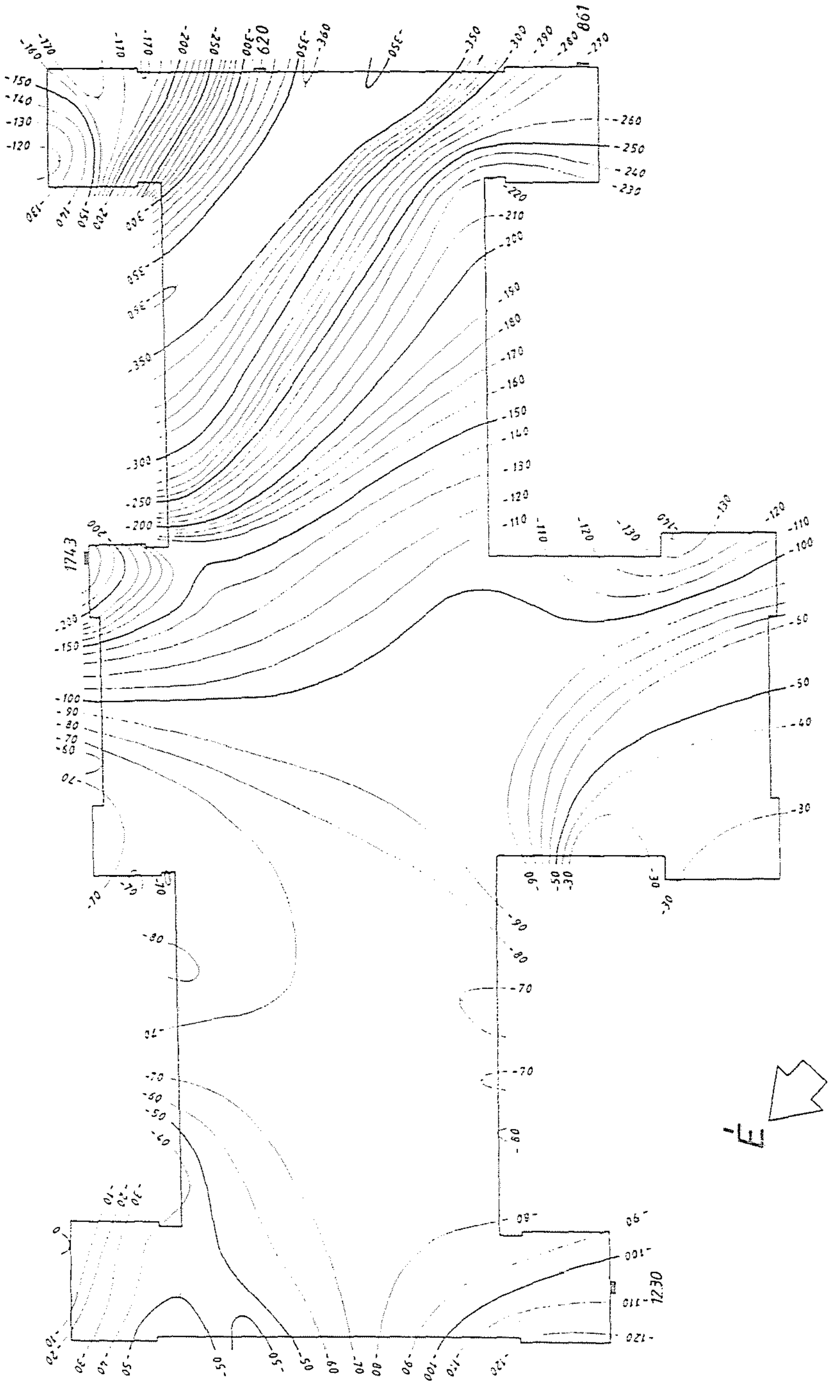

Fig. 1. Isolines of uneven subsidence according to levelling results of the rim line

subsidence of rims, which can be seen on the Figure, can be taken as equal to the irregular subsidence of outer walls and foundations of the building.

Where the isolines are the most dense there are the critical sites, which are indicated otherwise by cracks in outer walls of the building.

This representation is very expressive but it is rather arbitrary regarding the interior of the building. Therefore we have drawn a plot to demonstrate the critical sites, which shows the irregular subsidence of only the outer walls (*Fig.2*).

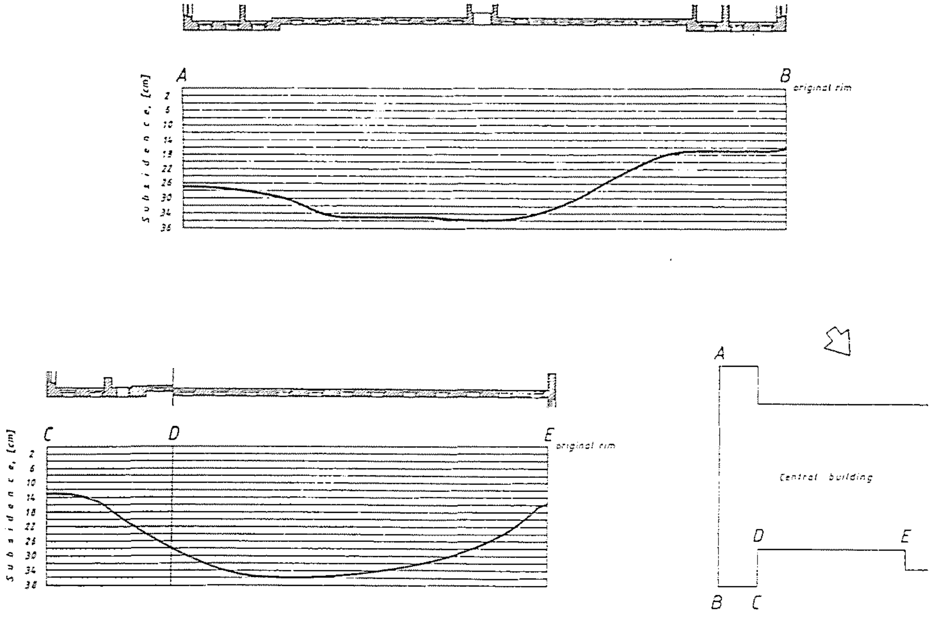

Fig. 2. Diagram of rim line deformations at critical wall sites

The unit of subsidence values on the diagram belonging to this Figure is cm.

It is apparent on both Figures that the uneven subsidence of outer walls is very significant: its maximum value (on the S end and SE part of the building next to the river bank) reaches up to 360 mm.

We used some results of diploma theses made by surveying engineering graduate students at certain dates between 1969 and 1982 (GULYÁS, 1969; BÉRCZI, 1979; ZAITOUNEH, 1982) to detect deformations of the interior of the building.

The purpose of these diploma theses — among others — was to detect vertical deformations of axes of inner passages at different floors of the Central Building, which took place since the date of construction.

Therefore we have measurement data in the 1909 – 1969 (60 years), the 1909 – 79 (70 years) and the 1909 – 1982 (73 years) time period for the deformations.

On the basis of the above measurement data isoline plots were drawn out of which here we present one referring to the 1909 – 1969 time period (*Fig. 3*).

Unfortunately these plots of movement cannot be combined with *Fig. 1* in order to fill into its interior more realistic details, because the diploma theses measurements were not connected to that certain rim that passes around; not only in 1991 but in reality at no time.

If, however, we consider *Fig. 3*, it can be stated that the characteristics and relations of deformations correspond well to the ones presented in *Fig. 1* which allows us to deduce that — disregarding for the differences one quite naturally expects — the deformations are basically the same for the outer walls and the interior parts of the building.

The results which were presented previously have two defects:

a) The results show only relative movements and it is impossible to determine with the aid of them to what extent the whole building has subsided in the past or how much it subsides at present.
b) Since the spirit levellings were not taken to first-order level marks, the identity of points between repeated measurements (in vertical sense) could have been made sure at most only with a few mm accuracy. This may bc enough to estimate great deformations occurred during a long period of time, but it is not accurate enough to detect precisely the deformations, which are continuing at present (and surely they are of relatively small size).

Hence our investigation has continued with tracking down data of such spirit levellings, which were taken to first order benchmarks, placed in the building at different dates and for different purposes.

Deformation Detection on the Basis of Past Time First-order Spirit Levellings

These spirit levellings are called mainly in the sense that

— the measurements were taken to first-order benchmarks,
— these points of the building were measured with respect to certain external first order benchmarks which can be considered free from

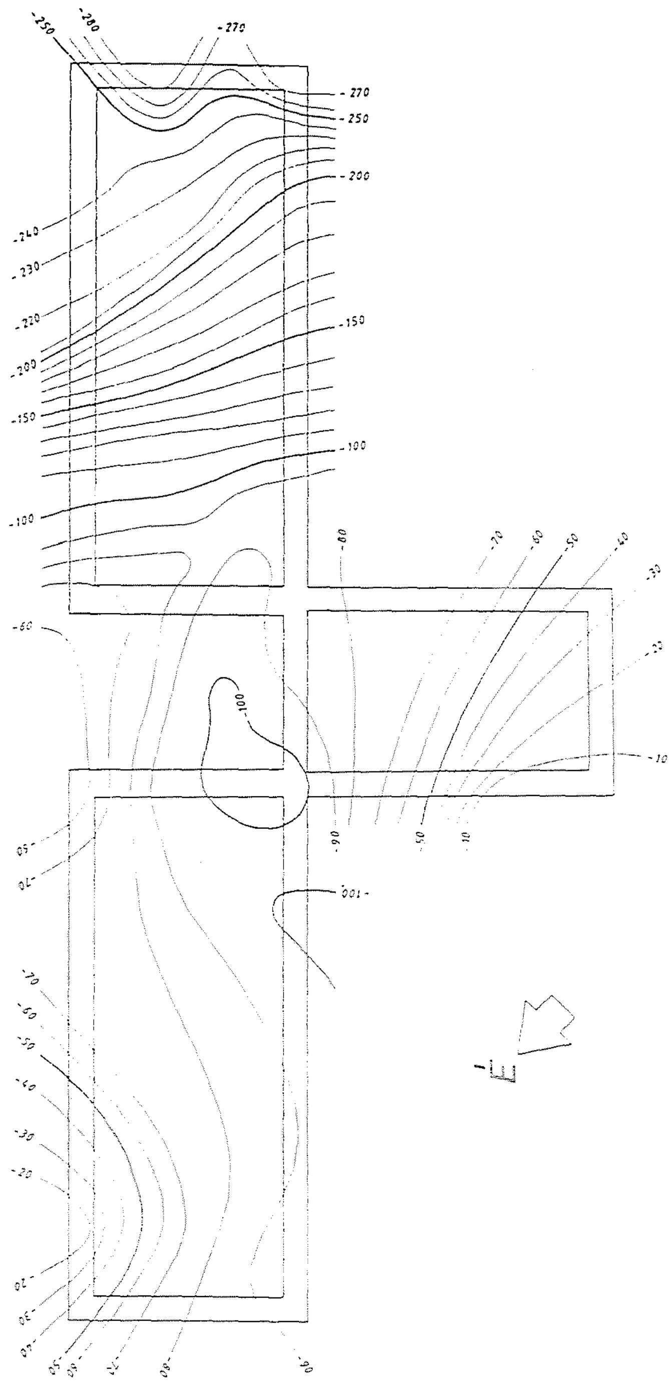

Fig. 3. Deformation of inner passage axis lines for the 1909 – 1969 time period

subsidence, so the absolute displacement (subsidence) of points with respect to those bench-marks can be determined.

There are altogether four first-order bench-marks located in the outer wall of Central Building (*Fig. 4*). These were established during development of the first-order levelling network of Budapest between 1932 - 1936 (GUÓTH, 1941).

The height of *bench-mark 1230* above sea level can be traced back in time to 1923.

The initial control station (base control stations) of the levelling network of Budapest, namely, was the very one established in the basement of the central building of Technical University as an independently founded concrete pillar of great mass. Its height above sea level was derived from the national base control station near village Nadap. At the same time it was connected with spirit levelling to both a steel rivet built into the outer wall of building, and a neighbouring bench-mark (approximately at 500 m distance) built into the rock of Gellért Hill. The standard bench-mark No. 1230., which was marked in 1936 was measured with respect to both of these stations and after this the steel rivet was destroyed.

Professor Oltay and his assistants made numerous measurements in the time period 1923 - 1949 for the above mentioned stations to check the immobility of the concrete pillar witness mark to the base control station. When they experienced that the very small movements of the pillar are in connection with the water level changes of the river Danube they bore drillings in the neighbourhood of building and they uncovered the stratification of subsoil (OLTAY, 1939).

In the following Table the movement of bench-mark 1230 is shown based on Oltay Professor the measurements during 1923 - 1949 and the graduate students'measurements during 1949 - 1991, respectively. The speed of the movement has been calculated as differences/year.

The bench-mark (and the wall portion represented) thus subsided rather steadily between 1923 and 1991, approximately 0.5 mm/year; in the time period 1961 - 1991 the rate of subsidence seems to decrease by a small amount.

The *bench-mark 1743* was marked during the years 1932 - 1936 while the levelling network of Budapest was established, near to the main entrance of central building facing the Danube. At that time its height above sea level was derived first. Its height was determined again many times later on: during 1954 - 1958 when new city levellings were made: in 1967 and 1969 during the preparation of diploma thesis, and between 1969 and 1991 many times when the movement of the retaining walls of the river Danube was under study.

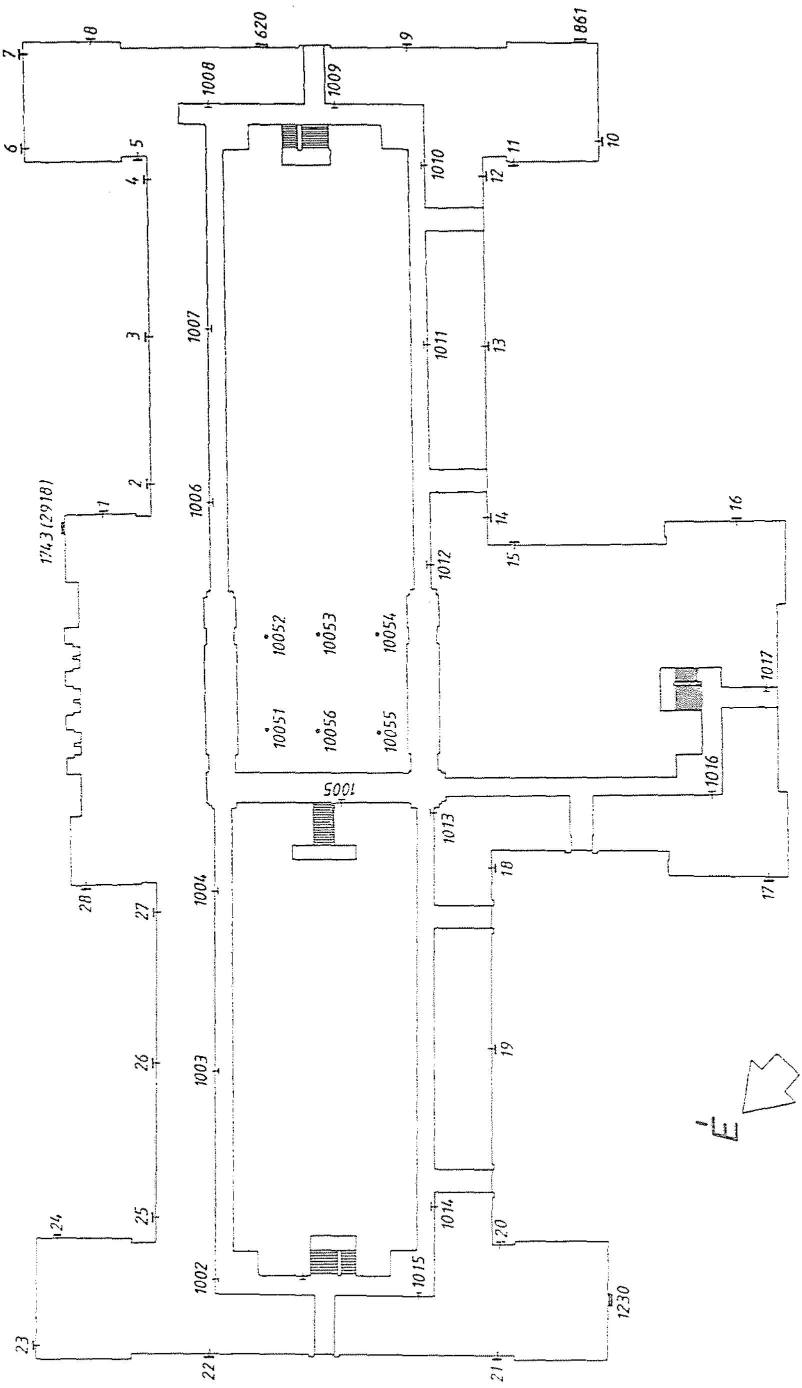

Fig. 4. Bench-marks along the outer walls and the basement passages

Table 1

Period	Time interval	Differences		Summarized		
				Time interval	Differences	
	year	mm	mm/y	year	mm	mm/y
1923 - 36	13	-6	-0.5			
1936 - 42	6	-3	-0.5	19	-9	-0.5
1942 - 48	6	-4	-0.7	25	-13	-0.5
1948 - 49	1	-1	-1.0	26	-14	-0.5
1949 - 61	12	-6	-0.5	38	-20	-0.5
1961 - 91	30	-9	-0.3	68	-29	-0.4

Table 2

Period	Time interval	Differences		Summarized		
				Time interval	Differences	
	year	mm	mm/y	year	mm	mm/y
1934 - 56	22	-14	-0.6			
1956 - 67	11	-7	-0.6	33	-21	-0.6
1967 - 69	2	-3	-1.5	35	-24	-0.7
1969 - 71	2	-2	-1.0	37	-26	-0.7
1971 - 73	2	-2	-1.0	39	-28	-0.7
1973 - 76	3	0	0	42	-28	-0.7
1976 - 79	3	-4	-1.3	45	-32	-0.7
1979 - 81	2	-1	-0.5	47	-33	-0.7
1981 - 83	2	-2	-1.0	49	-35	-0.7
1983 - 85	2	-2	-1.0	51	-37	-0.7
1985 - 87	2	-1	-0.5	53	-38	-0.7
1987 - 89	2	0	0	55	-38	-0.7
1989 - 91	2	-2	-1.0	57	-40	-0.7

Table 2 shows the movement of bench-mark based on the above measurements.

The bench-mark (and the wall portion represented) thus subsided steadily between 1934 and 1991, approximately with speed 0.7 mm/year.

The *bench-marks 620* and *861* were established no doubt during 1932 – 1936 but their heights were determined neither then nor since that time. (The possible cause of their establishment will be mentioned later.)

Table 3

Period	Time interval	Differences		Summarized		
				Time interval	Differences	
	year	mm	mm/y	year	mm	mm/y
1968 – 69	1	–4	–4.0			
1969 – 78	9	–11	–1.2	10	–15	–1.5
1978 – 91	13	–18	–1.4	23	–33	–1.4

Students preparing their diploma theses determined their heights above sea level a few times. *Table 3* shows differences of the bench-mark 620 based on the above measurements.

Table 4 then, shows movement of the bench-mark 861.

Table 4

Period	Time interval	Differences		Summarized		
				Time interval	Differences	
	year	mm	mm/y	year	mm	mm/y
1968 – 69	1	–4	–4.0			
1969 – 78	9	–4	–0.4	10	–8	–0.8
1978 – 91	13	–12	–0.9	23	–20	–0.9

The members of the Department of Geodesy developed a deformation detection network of 17 first-order bench-marks in 1979 (see stations 1 – 17 in *Fig. 4*).

The heights of bench-marks were determined by graduate surveying engineering students who were preparing their diploma thesis in years 1979, 1982, 1984, 1987 and 1991 (BÉRCZI, 1979; ZAITOUNEH, 1982; SÁRKÁNY, 1984; SURUR, 1987; TOLNAY, 1991).

One of the three isoline plots, drown on the basis of the results, is presented in *Fig. 5*, which shows the subsidences occurred during the period 1979 – 1991 in mm units. The subsidences here too, are referred to the Gellért Hill bench-mark which was supposed to be motionless.

The magnitude and spatial distribution of subsidences, which can be seen on these isoline plots show good agreement to the subsidences of four outer wall bench-marks.

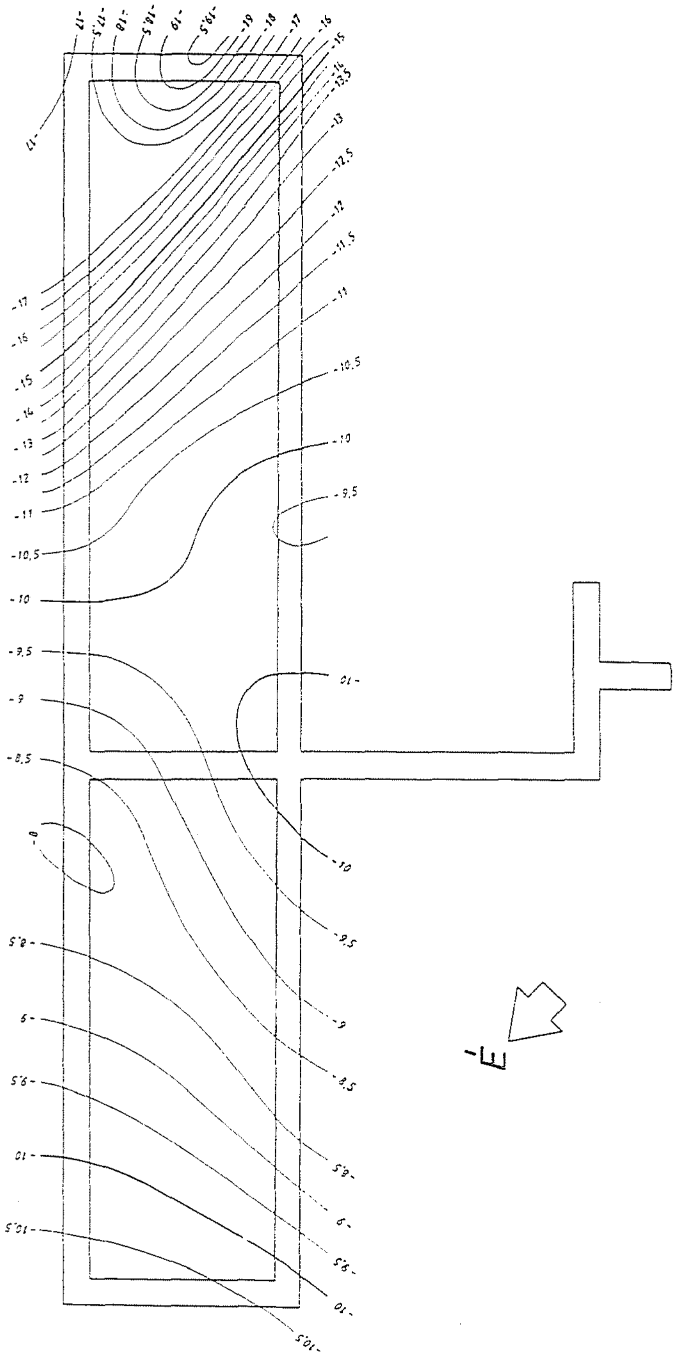

Fig. 5. Isolines plotted on the basis of basement bench-marks for the 1979-1991 time period

Conclusions Drawn on the Basis of Deformation Detection Study Results

1. It can be concluded that the pictures of relative and absolute movements presented are very similar to each other: both show unanimously that the NW and central parts of the building subsides moderately and the SE part subsides heavily.

2. As it was presented, the subsidence of certain wall portions of the building can be detected by accurate surveying methods, too from 1923. Both the absolute and the relative speed of subsidence according to these accurate measurements amounts only approximately 1 mm/year from 1923 up to present. This means that altogether 68 mm mean absolute and relative subsidence took place in the time period 1923 – 1991 (in 68 years). From this follows, then that at least 80% of the 360 mm relative (and, no doubt, of the absolute, which is proportional to this) occurred between 1909 and 1923. (This is roughly in accordance with the usual stabilization process of buildings.)

If this is the case then similar cracks had to be seen in both the outer and inner walls along the twenties as nowadays. At that time no doubt it was noticed and probably subsidence measurements were taken as well.

We have not found such measurement results but it is likely that the bench-marks 620 and 861 (*Fig. 4*) were established during the years 1932 – 1936 for deformation detection reasons, for they were not placed uniformly distributed but close to each other just at the critical wall sites.

The speed of subsidences is uniform disregarding of small fluctuations and this means that the character of subsidences is of a linear and not stabilizational kind, based on the measurements that can be traced after 1923. Some change occurred in the subsidence speed of wall rivet No. 1743 since 1967, which possibly can be attributed to the load increasing effect of garret-space building up in the SE connecting wing during the years 1963 – 1964. On the other hand the comparison of subsidences measured along the footing line and the frontal cracks proves unanimously that the building damage is of a subsoil origin (BICZÓK, 1991).

3. The detection of reasons of the very great uneven subsidences is not the task of deformation measurements, hence we contribute only some details on the basis of last century maps available to us.

We present a map portion of the site made in 1870 (VARÁZSDI, 1870). The present location of the central building is indicated here. It can be seen that the 2/3rd part of the building lies in the former bed of Danube, mostly that part of the building which subsides the most heavily (*Fig. 6*).

A dam was built according to the lay-out plan of Danube, after which the remaining water surface was termed Lake Lágymányos. The central

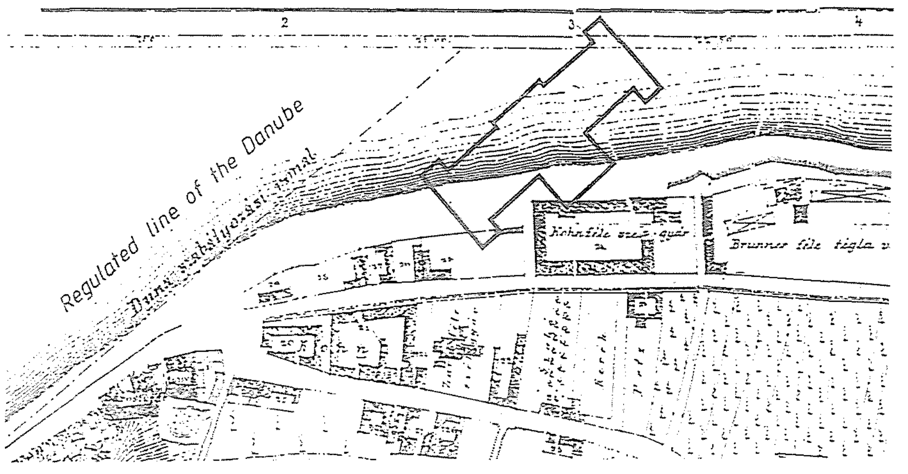

Fig. 6. The present position of central building overplotted on the map of Varázsdi, L., year 1870.

building (most of its part) was built over the filled bed of northern end of this lake.

4. It is a very important lesson of the investigation shown here that the subsidence has not stopped but continues recently as well. (See the Tables shown).

Therefore the necessity of continuation of observations can be of no doubt. The recent uneven subsidence, that is to say, upsets the balance of endangered building parts more and more and decreases their stability.

The long period observation and deformation detection measurement sequence made it possible to predict the likely subsidence of the building and to estimate the date when the extent of damages in the structure will harm the building.

During the evaluation of subsidence measurements and soil mechanics investigations members of Department of Geotechnics plotted the subsidence line of southern frontal footing (BICZÓK, 1991). They showed that the relative angle deflection corresponding to 15 cm bending is at present

$$\tan\alpha = 15/2900 = 1/190 .$$

The critical angle deflection needed for the constructional damages to be serious is 1/150, which arises at 19 cm bending inwards at the given length. (*Fig. 1*, *Fig. 7*). If the character of subsidences will not change (since there is nothing against this) then the expected line of subsidences belonging to 19 cm bending can be drawn. The movement of the four wall rivets can be plotted versus time and since the character of movement is the same for each curve the date of time can be read from the extrapolated curve when occurrence of the critical subsidence is probable (BICZÓK, 1991). The expected subsidence of the two rivets in southern fronting is shown in *Fig. 8* (28 and 37 cm).

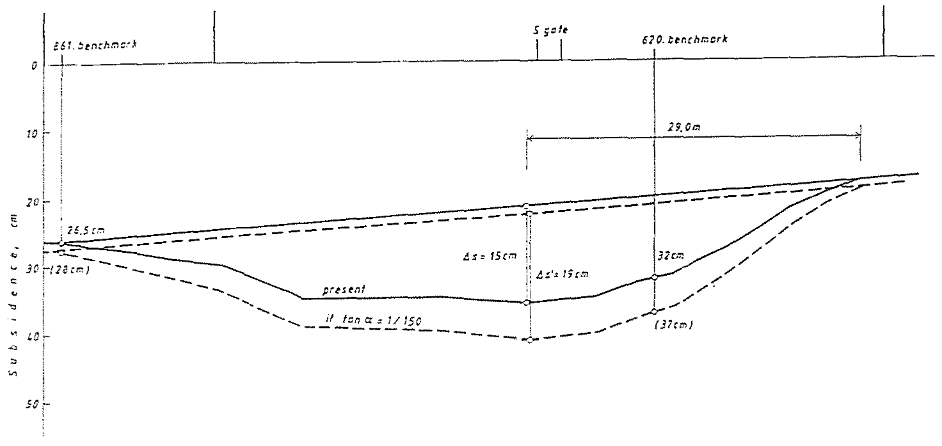

Fig. 7. Deformation lines of S fronting of the building

The investigations make it probable that if subsidence of the building continues at present rate the southern part of building will be in critical state after 25 – 30 years. Therefore during the next years reconstructional works have to be initiated to stabilize the building.

Deformation Measurements in the Future

According to the idea of movement of building deduced, we added some new first-order bench-marks to the old ones (basement stations and the 4 stations in the outside wall) in 1991.

We established 28 first-order bench-marks in the outer footing of the building and 6 first-order bench-marks in the footing of storage room under the hall. Their heights above sea level were derived from the height of bench-mark in the rock of Gellért Hill.

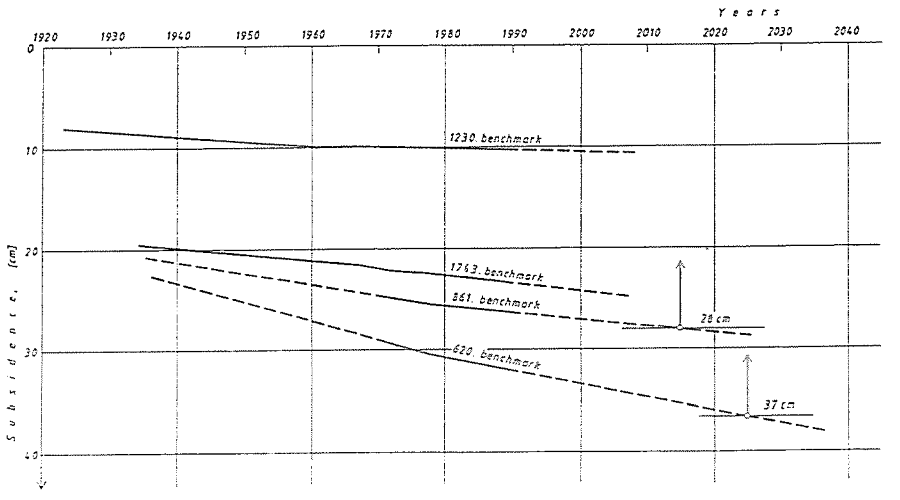

Fig. 8. Expected time for occurrence of critical subsidences

We developed thus a substation net which will enable us in the future to observe subsidences of outer and inner loaded walls even for short periods (e.g. 1 year) of time with sufficient accuracy in both relative and absolute sense.

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