Preservation of Old Buildings on the U.S.S.R. Territory

Sauvetage des Bâtiments Anciens sur le Territoire de l'URSS

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SYNOPSIS The problem of adaptation of "ancient building - foundation - soil base" system to new rapidly altering environment of contemporary towns is considered in general terms and is based on examples in the European part of Russia. Essential features of soil conditions and their present changes are described. The design of buildings and foundations reflecting the peculiarities of the Russian national building tradition is presented. The methods for saving structures and sites applied in the Soviet Union are analysed. The deformation history of the leaning tower of the Nevyansk town in the Urals is given as an example.

1. ESSENTIAL FEATURES OF BASES AND FOUNDATIONS OF ANCIENT BUILDINGS

Geotechnical conditions of the Russian plain have some characteristic features. Soil bases are mainly composed of soft soils. Weak soils are most common. There are, however, some areas covered with glacial moraine and composed of exposures of horizontal layers of palaeozoic rocks. Groundwater lies near the surface. Soils get frozen to a considerable depth. Tectonic motions are slow. Seismic activity does not exceed magnitude 6. These conditions greatly differ from those of the Byzantine Empire, the Balkans and Italy where some models of monumental structures were borrowed by Kiev Russia and the Empire of Peter the Great. Our own Russian architectural tradition is preserved in wooden structures to this day. They are rather light and having the height up to 50 metres resist non-uniform settlements very well owing to their structure being made of some prefabricated frameworks. But they easily catch fire. That is why since the Xth century monumental structures in Russia have been made of stone. Adaptation of "standard designs" to local conditions was developing along two main lines. First, the architecture of buildings was changed to a certain degree. Secondly, the design of buildings and their foundations was adapted to local ground conditions. Trying to preserve some constructive features of buildings which are particularlyessential for religious structures builders chose the way of land-reclamation and increasing structure rigidity.

During eight centuries land-improvement was mostly carried out by means of soil solidification with piles 1-1.5 metre long. Over the heads of piles rubble or field stone was laid in trenches which were filled with white lime. A strip foundation was made at the depth of 1.5-2 metres that eiliminated soil freezing under it and provided long-term conservation of piles in groundwater. In the XIXth century under strip foundations wooden sleepers were laid instead of piles which redistributed loads in heterogeneous weak soils and prevented them from non-uniform settlements.

The latter exert extremely distructive influence on the religious memorials because of their unit rigidity providing horizontal force resistance in the vaults and actually eliminating non-uniform settlement. This fact causes static undeterminability and unalterability of the "ancient building - soil base" system. For the preservation of the unalterability of this system a reliable stable base is necessary.

Soil conditions of structures were generally taken into account. Margin of safety was not provided for. The New Herusalem Monastery of the XVIIth century near Moscow may be a good example ofit.

The floor of the underground church which was a copy of the Jerusalem protolype is situated only 40 cm above the groundwater level. Groundwater is in sands and its level is determined by the Istra River. This is responsible for normal moisture regime in the building. In the monastery ensemble there is a cylindrical rofunda of 22 m diametre and 40 metres high built above a small chapel ("kuvukleya"). The rotunda ring foundation exerts average pressure on the ground which is greater than the design one for soil base. Only with due consideration to combined behaviour of the foundation of the heavy rotunda and the small chapel situated in the centre of the ring foundation the design pressure carried by the ground appears to be higher than the pressure of the two buildings.

Undamped settlements of many structures taking place for centuries and the damage of the uncompleted Assumption Cathedral of the Kremlin in May of 1474 during a weak earthquake are a sign of the absence of margin of safety. Sometimes the bearing capacity of a foundation and ground was overestimated (section 5). The absence of margin of safety resulted in settlements which did not cease during three of four hundred years (for example the Poteshniy Palace in Moscow built on made ground). Ruptures of massive wails of the Troitse-Sergiyev Monastery near Moscow attained several decimetres during the last four centuries. Its walls were erected on clay soils.

Contemporary intensive alterations of ground conditions have resulted in increasing deformations observed earlier and new ones. Therefore soil and foundation engineering activities are necessary when the "old building - foundation - base" system is concerned.

2. THE MAIN WAYS OF SAVING ANCIENT BUILDINGS IN ALTERING CONDITIONS OF CONTEMPORARY TOWNS

In contemporary towns the changes of soil conditions are the following: 1) lowering the groundwater table, accopanied by pile decay and sand compaction; 2) soil compaction as a result of heavy loads exerted by new heavy buildings; 3) dynamic loads caused by traffic; 4) activizing the physical and chemical internal erosion.

In addition to the changes caused by the construction activities of the XXth century there are also changes which have been piling up during the history of these buildings. Such is level rising of made ground (cultural stratum) which covers the building plinth and gives rise to overmoistening of walls etc. The site lowering caused by neotectonic process occurs not so often. For instance the sinking of the Mirozhsky Monastery territory in Pskov at the rate of 2-3 mm a year during its eight century existance resulted in frequent inundations by the Velikaya River floods.

In our efforts to save buildings we generally have no intention to save foundations which are archaelogical values as well. The main trends of building protection are as follows:

1) raising and shifting them from the areas with adverse conditions to new places; this method is valid for the restoration of the architecture and temperature and moisture content regime of buildings some part of which is concealed by the cultural stratum (section 3);

2) isolation of the base of an ols building from active zones of new structures for eliminating their static and dynamic influence on the monument (section 4);

3) chemical stabilization of soils and foundations, pile insertion into the base, application of cast-in-place bored piles, strengthening of overground structures.

Some methods of saving buildings are considered below.

3. RAISING AND SHIFTING OF BUILDINGS

In the last century few-storeyed dwelling houses, cultural and educational buildings and trading centres were erected. Nowadays in the centres of many towns there are a lot of buildings of this kind. This leads, however, to irrational utilization of town territories.

As a result of the growth of towns the problem of widening thoroughfares and increasing the number of storeys becomes very topical.

Then widening thoroughfares it is reasonable to shift good sound buildings and to raise them for building additional storeys under them. The frame for shifting stone houses having no build ing framework must consist of wallbeams driven into the chief walls. At that the wallbeams of the walls parallel to the movement direction are driven one layer below wallbeams which are transverse to the wall movement direction. Besides, is the building is the building is shifted obliquely or with a turn special cushions are inserted under the lower wallbeams. Under the wallbeams or cushions tracks are laid with rollers placed on them. The same frame is used for shifting and raising. The lifting of the building is carried out by hydraulic jacks of the "Perpetuum" system. When the building is lifted by jacks they are provided with cages made of 1,2x1,2 metre metal beams located under them. Such dimentions of the cages add to the stability of building. Steady lifting is achieved by means of autonomous system of water levelling. The distance between the hydraulic jacks whose carrying capacity is up to 3 000 kN may vary from 6 to 10 metres.

The raising design takes into account the function of the building. Besides, its lay-out and architecture may be improved. The cost of the saved building is summed up with the cost of raising.

Additional expenditure on lifting by hydraulic jacks with centralized feeding system equals or only slightly exceeds the cost the roof alone. When a building is being raised the tenants do not move out. This practice in the USSR has proved correct. The cost of the shifting and subsequent raising does not exceed 50 per cent of the estimated cost of an ordinary building.

In our opinion few-storeyed buildings may be raised up to 20 metres and 4-6 additional storeys may be built under them. Under favourable territorial conditions the raised buildings may be placed on stylobate. In this case the raised building is propped up with columns.

A building may be raised without shifting, then additional storeys, pavements and transport passages are constructed under it. This does not require additional expenditure on strengthening foundations because when a building is raised the foundation is further forced into the ground which results in increasing bearing capacity of the subsoil.

4. PERFORMANCE OF NEW BUILDINGS NEAR OLD ONES DURING TOWN RECONSTRUCTION

Inspection of many buildings erected in Leningrad on a thick layer of weak soils before the beginning of the XXth century has shiwn that in the wall brickwork there are some fissures which propagate much more in the butts of buildings where they border on adjacent houses. This wall demage is the greater, the more storeys the new building has. Basides, the amount ofnatural building settlement, non-uniform settlement progress, the construction history which influences the base consolidation and the walls and the foundation are of considerable importance. The application of reinforced concrete, steel framework in the brickwork, devision of a building by settlement seams into blocks which was often the case in the second half of the current century has positively inflyenced the behaviour of the structure.

Experience shows that if the natural settlement of a building exceeds 10-15 cm the influence zone of the adjacent building extends for 20-30 metres depending on the depth of weak soils, but the most dangerous are additional settlements which occur in the immediate 5-6 metre proximity to the new buildings.

In foundation design the Constructional Standards and Rules of the USSR (1975) and other countries (Bazant, 1979) reguire estimating the foundation deformation. Basides, the following condition must be satisfied:

$$S \quad S_{ult} \qquad (1)$$

where S is predicted base settlement, S_{ult} is ultimate deformation (defined by the standards or estimates with the allowance for the materials, structure and function of the building.

If there are some old buildings whose structure is not supposed to be damaged when constructing new buildings on adjoining plots of land, the condition becomes:

$$S_{add} \quad S'_{ult} \qquad (2)$$

where S_{add} is additional settlement of the adjoining construction site, S'_{ult} is ultimate additional settlement of the old building.

It is difficult to determine S' ult as the structure of old buildings has some degree of decay. That is why S ult is defined empirically from the results of in-situ measurements and observations. Table I* gives the values based on the investigation of building experience in Leningrad compared with ultimate foundation in deformations of isolated houses.

These data indicate that in the case of adjacent buildings the requirements as regards to their bases and foundations should be more rigid than those to isolated buildings. Hence their performance calls for additional expenditure.

Pile application when constructing new buildings near old ones is very expensive as their driving is out of the question.

Consequently we may obtain the best results taking simultaneously some of the measures connected with the lay-out of the building, its architecture and structure (including underground structure), organization and technology of the building process. When determining what measures are to be chosen we must be guided by the anticipated value of medium settlement of the foundation of the building designed. If S 4-5 cm simple measured for controlling soil base are sufficient when construction work is under way. When S 5-10 cm simple technological procedures may be applied including the use of cantilever beams in the zone of adjoining whose span may equal 2-6 metres, soil stabilization or preventive strenghtening the structures of old buildings. If settlement exceeds 10 cm pile application and deep supports resting on dense subsoil including diaphragm walls is inevitable. The usage of such foundations, however, demands due precautions when precise geodetical measurements of the settlement of the existing buildings are taken.

5. DEFORMATION OF THE STRUCTURES AND FOUNDATIONS OF THE NEVYANSK TOWER

The Nevyansk tower is a unique monument of architecture of the XVIIIth century. It is wellknown in our parts as a Leaning Tower with apparent western inclination. There are two hypotheses concerning the cause of its inclined state:

1) the deformation of the weak subsoil;
2) the inclined tower position was meant when it was under construction.

The tower (fig. 1) 54 metres high was built not earlier than 1725 and not later than 1742. It was made of brick and has a square cross sec-

TABLE I

Admissible Ultimate Deformations of Old Buildings

The kind of foundation deformation	Isolated houses with stone walls without steel reinforcement		Old houses with stone walls without steel reinforcement, partly decayed		
	According to the USSR Construction Standard and Rules (3)	According to Z.Bazant	I degree of decay	II degree of decay	III degree of decay
Average settlement	10	10	5	4	3
slope	0,050	0,0013	0,003	0,0015	0,001

I degree - there are no fissures; II degree - there are some fissures in separating walls; III degree - there are some fissures in bearing walls

*Contributed by Prof. B.I. Dalmatov and ass. prof. A.A. Sobenina tion of 9x2 metres up to the height of 24 metres, and further it is octahedral. The tower is crowned with a octahedral tent 8.8 metres high. A brick two-storeyed annex 6.5 high with a porch adjoins it in the south-east. The total mass of the tower is about 30 000 kN, the centre of gravity is at the height of 14 metres from the height mark of the foundation. The latter is a strip foundation about 2.5 metres wide made of rubble.

The geotechnical survey which involved boring nine boreholes about 20 metres deep, sampling, probing and pressuremeter tests has revealed that the site consists of alluvial and alluvial-diluvial loams of tough and plastic consistency. The soil compressibility is defined by the modulus of deformation equal to 3-10 kMPa, cohesion ranges from 0,024 to 0,30 MPa and the angle of internal friction is about 25-28 degrees. The loams are covered by a layer of made ground the footing of which within the bounds of the tower outline is at the depth of 6-8 metres. The groundwater having hydraulic connection with the neighbouring pond is at the depth of 3,0-3,1 metres from the surface.

From the data of geodesic observation which have been made since 1962 the tower settlement

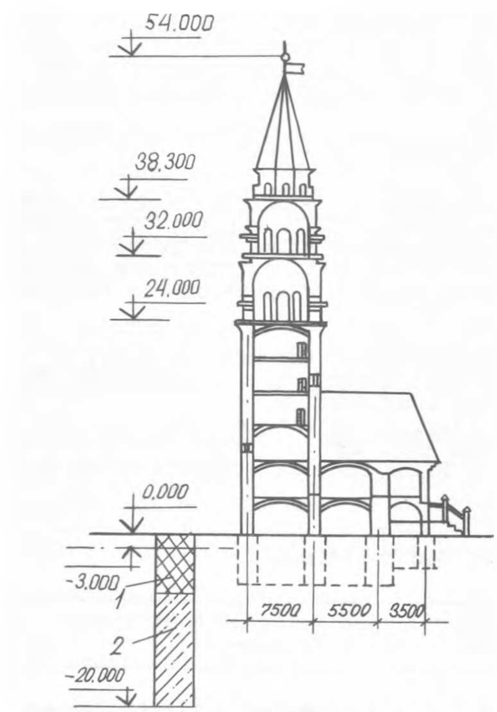

Fig. 1. The Nevyansk Tower Section

1) made ground
2) alluvial-diluvial quaternary loam

occurs at the rate of about 0.9 mm a year. The deviation of the tower top from the base centre equals 1800 mm. The deviation of the tower stem is also proved by the fact that the floors of the storeys, the vault stringers over the apertures have different inclinations.

The deformation nature testifies to the incline formation and efforts of its elimination made during the tower erection.

We take the view that the most probable reason of the tower inclination is unfavourable geotechnical conditions of the construction site. The stratification direction and the soil bedding depth indicate that the tower was most likely built near a former river-bed which was later filled in. The tower incline on the whole corresponds to the incline direction of the natural soil and is accounted for by the deteriotation of soil characteristics in the drection of the river-bed which is quite natural under the conditions.

So the loam moisture content at the depth of 6-7 metres increases in the direction of the incline in the range of 0,22-0,29 per cent and loam compressibility increases accordingly.

There is no immediate threat of the tower collapse in its present state. The 0.9 metre displacement of the centre of gravity with respect to the tower base has not resulted in tensile stress in the brickwork and under the foundation base. Moreover, according to the observation data progressive increase of the tower inclination rate does not occur. Soil settlement which is going on at present is due to rather weak soil base, the consolidation of rather weak soil base referred to as "old age settlement".

Further built-up of the tower stability and the settlement stabilization is connected with the elimination of the unfavourable factors which attend its maintenance. These factors are supposed to be eliminated when the tower is restored. The following measures are proposed: 1) the lowering of a rather high vibration level produced by railway transport; b) elimination of the danger of internal erosion by cessation of groundwater pumping out of the nearby sump; c) prevention of the tower plinth decay by 1 metre surface level lowering near the tower and arranging overground water runoff; d) elimination of fissures in the annex and porch which occurred during non-uniform deformation of the separate elements of the tower.

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