Saving Cities and Old Buildings — General Report

Sauvetage des Cités et des Bâtiments Anciens

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INTRODUCTION

I would like to congratulate the I.C.S.M.F.E. Committee on having the foresight to introduce an entirely new session at this Conference - that of "Saving Cities and Old Buildings". Professor Smotczyk has already emphasised, in his Comprehensive State of the Art Review, that this is a field with great scope for ingenuity and innovation within Geotechnical Engineering. It is also one with direct and immediate social consequences which offers us an opportunity for very favourable public exposure of both our art and our science. It is particularly relevant to the Conference that major contributions have been made to this Session by Swedish engineers working on an ambitious preservation scheme for Old Stockholm.

As co-reporter for this session, I had high hopes that we might receive a stimulating set of papers which not only enlightened us on the skills of past generations of geotechnical engineers, but also offered exciting and informative accounts of how some of our great international monuments were being examined, analysed and preserved, or re-founded using the very best of our skills and ingenuity. Alas, this has, in my opinion, not happened and, with a few notable exceptions, the 29 papers accepted for this Session form a polyglot collection of short (typically 3-4 page) notes on a range of topics so wide as to preclude all but the crudest distillation of their collective essence, let alone provide a general, useful body of experience in each of the three fields outlined in the brief for this Session. (For brevity, papers will frequently be referred to by the number allocated to them in the list of Contents to Session 9).

Even setting aside the obvious lack of consistency within National Committees - for example in accepting; (i) "old" as 10 years (3), or, (ii) that, in two pages, it is possible to provide other than superficial enlightenment on "Settlement of loaded Loess and its silication" (28) or "Problems of the Akropolis Rocky Hill" (17) - the possible diversity of topics within the three specified fields:

(a) Geotechnical problems connected with the protection of existing structures against subsidence and floods.

(b) Investigation of the integrity, durability and bearing capacity of structures.

(c) Underpinning and other methods of saving structures and ground.

is far too wide to be usefully encompassed within one session. It might, perhaps, be useful to look at a rather different grouping of the topics which fall within the Geotechnical aspects of the theme "Saving Cities and Old Buildings" such as,

1. SAVING AND/OR PROTECTING; either whole cities (or parts thereof) or single structures (structures rather than buildings for we have in the current Session papers on a bridge (27), a drydock (26) and early Egyptian cliff tombs (9)) from -

2. HAZARDS; of which our main concern would be with floods, regional subsidence, failing foundations and modern development. All of the papers in this Session, apart from possibly those on Pisa (Croce et al (8)), the Mexico National Palace (Alberro and Hannell (1)), old cellars in Budapest (Gabos and Nagy (15)) and Ortigosa et al (21) would be grouped in the failing foundations category. [Ortigosa's paper deals with underpinning problems arising from the construction of adjacent underground car parks and is the sole paper entirely concerned with modern development.] In the treatment of failing foundations there are two main phases -

3. (i) INVESTIGATION; which comprises the location, recording and mapping of foundations, their examination and testing together with the corresponding records of the ambient soil and groundwater conditions. This would be followed by their -

   (ii) TREATMENT; which, depending upon the severity of the problem will be one or other of preservation and protection, or repair and reinforcement or replacement by an alternative foundation system.

There are clearly a very large number of valid, single topic selections from this list, even though section 3 refers only to failing foundations, and it would therefore be prudent for future Conferences to devise a much more limited brief for Contributors.

However, my task is to report on the 29 papers accepted, the majority of which refer to underpinning either specific structures or to groups of structures within a city. In addition to the subsidence papers already mentioned, three others concentrate on very detailed mapping and recording of foundation data over large areas of cities in Sweden, Finland and Germany (4, 2, 11). There are three papers which deal principally with specific underpinning techniques (13, 16, 27) and two which provide information on the decay and preservation of timber piles (19, 23).

FOUNDATION MAPPING FOR CONSERVATION

It is only possible to rationalise any conservation programme if very comprehensive data are available on the subsoil conditions (including groundwater regimes and their variation), the location and form of existing building foundations (and the remains of earlier constructions) and the basic mechanisms which underlie the deterioration of the supported structures. Three of the papers presented describe major contributions in this field. They are those of Bohm and Pranborg (4), who deal with the mapping of Old Stockholm, Anttikoski and Raudasmaa (2), who present similar results for Helsinki, and Drescher (11), a less detailed account, which focusses on the dramatically variable salt-dome geology of Lueneburg (FRG).

The latter paper is concerned with the relatively rare problem of subsidence generated by the erosion of salt caverns, their eventual collapse and the formation of sinkholes. Since 170 buildings have had to be abandoned and demolished over the past ten years due to excessive deformation (for example up to 300 mm vertical movement was recorded between 1961 and 1971 together with comparably large lateral movements), a survey has been completed dividing the city into 5 zones within which different orders of settlement hazard exist. It is of interest to note that the large lateral displacements are related to the presence of steeply dipping strata. Rather similar movements are mentioned by Bohm and Stjerngren (5) originating at the steeply dipping interface between the Stockholm gravel esker and the later marine deposits.

In common with the Bohm (4) and Anttikoski (2) surveys that in Lueneburg also resulted in modified building regulations which restrict, for example, the construction of cellars and deep basements and, in some areas, the use of piles.

However, the most remarkable and detailed maps are those of Old Stockholm and Helsinki which, in each case, have resulted in comprehensive Geotechnical maps (1/10,000), many other large scale maps (e.g. in Helsinki 690 at 1/2000 or larger) and detailed "house by house" information which is all used extensively as a reference base for any underground construction activities in the cities. Gabos (15) also mentions that similar Geotechnical maps have been compiled in Hungary. In addition to the shear scale of the investment (Anttikoski quotes 130,000 drill holes, more than 300 monitoring tubes and 40 settlement gauges) it is interesting to see that, in both cities, building owners have been awakened to the vital importance of the foundations of their buildings through public campaigns on groundwater levels, owner involvement in foundation investigations, legislation concerned with permission to repair foundations, etc. Groundwater levels are of particular interest because, in addition to the obvious settlement hazard, the majority of the early buildings are supported by timber piles which decay rapidly when they are exposed above the water level. (Technical information on the decay of timber piles is provided in the papers by Lundstrom (19) and Peek and Willeitner (23)). Hence the restrictions on deep basement construction, concern over tunnels and deep trenches generally and (in Stockholm) the introduction of experimental groundwater recharge schemes, some of which are based on water injection vertically upwards from tunnels (25).

One of the more remarkable features of the surveys is the speed with which they have been accomplished, in particular that in Stockholm - between 1974 and 1980. In Helsinki detailed foundation maps were added, between 1977 and 1980, to groundwater mapping, begun in 1972, following extensive soil surveys which started in 1955. Rather less extensive surveys of soil-foundation systems under cities are also reported by Gabos and Nagy (15) in Budapest and Palka and Zmudzinski (22) in Cracow.

SAVING OLD STRUCTURES

The most convenient categorisation of the remaining papers, which, with few exceptions, are concerned with failing foundations, is to divide them into those dealing generally with parts of cities and those which focus on single structures.

City Areas

Perhaps the most striking point is the uniformity of the foundation problems in many towns with buildings a few hundred years old. The most common feature being rotting timber piles, (sometimes used in densely packed rafts and only 1 - 1½in long (6, 16)), caused primarily by groundwater lowering, often by inadvertent drainage. In Stockholm this is aggravated by land uplift (about 4m/year).

There are papers describing numerous foundation repair schemes in Germany (16, 24), Sweden (5, 12, 25), France (13), Finland (2), Russia (6) and Hungary (15), some of which are essentially catalogues of well-established techniques applied to various old buildings. Piled underpinning systems are mentioned frequently and one innovation worth noting is the use of very small diameter piles for this purpose. Hilmer (16) calls 240mm diameter steel piles (supporting about 500kN) "small" and Comte (7) calls his, 120 - 150mm diameter x 11m long x 200kN, piles "micro"-piles, but the really small piles have been developed in Sweden. Bohm and Stjerngren (5) describe sectional, plastic covered, 76mm diameter, grouted, steel piles (typically 4m long and carrying up to 140kN). However, Eriksson et al (12) provide the most detailed information on such piles including load test data on a 76mm diameter pile, driven by a hand-held pneumatic hammer, and an even smaller 50mm diameter x 17m long x 500kN injection pile. In this case the pile is inserted inside the casing, in a drilled hole, and cement injection grouted at, or just above, the pile tip so as to establish a load carrying, grouted zone in granular soil of sufficient length ahead of the pile - in the above example there is approximately 10m of 50mmϕ pile tube and 7m of grouted sand/gravel. All these tiny piles appear to be easily installed and, clearly, have very wide application in underpinning small structures, indeed, Sundquist and Broms (25) mention that about 100km of such piles have already been installed in Sweden. Palka and Zmudzinski (22) describe, briefly, another new piling technique in which an enlarged base is formed by wedging open a conical pile and then grouted solid.

Diamanti and Soccodato (10) provide a detailed account of the problems of S. Leo and Orvieto - two historic Italian towns sited on the top of deteriorating rock masses. In both cases, very extensive and highly instrumented cliff stabilisation schemes have just been launched. Loizos' (17) paper on the rocky hill of the Akropolis indicates that rather similar problems are developing there also.

Two of the papers - Gabos and Nagy (15) and Palka and Zmudzinski (22) - referring to Budapest and Cracow, are concerned with interesting problems which have arisen from man's subterranean workings at earlier times. Gabos is concerned with very extensive (250km), deep (6 - 20m) 17th/18th century cellar systems (there were about 4500 individual cellars, each of them some 6 - 15m^2 section and 30 - 4m long), and Palka's problem is rather similar, but less widespread, involving about 15km of early 19th century, rectangular (some 1 - 2m^2 section) sewers and isolated, deep (8 - 12m) sumps. In both cases the problem was mainly one of locating and backfilling the old structures to remove any subsidence risk to newer buildings above. In Hungary major cellar-collapses began in 1970 and from 1974 intensive location (Gabos reports lack of success using geophysical methods, simple drilling and probing being more reliable) and backfilling operations were started using a range of plasticized cement mortar; hydraulic fill and pumped concrete techniques.

Individual Structures

Within this category we have specialised accounts of underpinning bridge pier foundations in France (Waschkowski et al, 27), the deterioration of ancient Egyptian tombs, caused by the expansion of shales due to water infiltration (Curtis and Rutherford, 9), and a brief analysis of an 18th century Turkish dry-dock which is still in everyday use (Togrol and Aksoy, 26). Again, the majority of the papers refer to rather conventional foundation repair operations. Some are, however, less conventional - Chernyshov et al (6) refer briefly to transportation of whole buildings for road widening - and here, the paper of Flores (14) stands out as he managed to lift a complete 18th century church through 3.5m.

His technique is to attach yokes at intervals around the walls of a building and, using interconnected hydraulic jacks working against pairs of tubular steel piles, jack-in the piles using the structure as kentledge. Eventually the church (58m x 17m) began to lift and, step by step, "climbed" 3½m up the piles - all 13,300 tons of it! Flores apparently lived to tell the tale and will undoubtedly have splendid slides of the building teetering in its temporarily suspended state. Pecero (20) provides a detailed account of a less spectacular levelling exercise at the National Palace in Mexico City where the building had settled 6m since 1900 (with some 2m differential movement) due to a reduction in the porewater pressures in the underlying soft clay caused by water extraction. However, the current pore pressure is apparently only about 1.3m of water below the hydrostatic value and trials are in hand to counter further settlement by injecting small quantities (0.4ℓ/s) of high pressure water, at depths of 7 - 25m, from small wells around the building. [Another high pressure (100 - 300 Bar) technique, is reported by Rizkallah (24), this time using cement grout, which is used to form "Soilcrete" grouted columns or 200mm thick wall elements as a simple vibration-free, minimum disturbance, underpinning system]. The generation of settlements by water extraction also forms part of the (Croce et al 8) paper on recent observations of the Tower of Pisa and the surrounding square. This is essentially a presentation of new settlement data which illustrates three main points; (i) that annual cycles of piezometric levels, due to pumping, appear to produce a "shake-down" effect of increasing subsidence; (ii) that the settlement is increasing over the whole area surrounding the Tower which moves in conformity with the general pattern; (iii) that the soil strata under the Tower are essentially of uniform thickness and, therefore, the major tilting was probably triggered by a quite minor initial irregularity.

The only other paper I wish to remark upon is that by Lord (18) which I consider to be the outstanding contribution to this subsection. His paper, which is longer than most, provides an excellent account of extensive underpinning operations on the 15th century York Minster Cathedral. In the paper the subsoil conditions are adequately described; the recorded data and the discussion of it is excellent (e.g. precise levelling of bench-marks was maintained at twice per week throughout the whole underpinning operation), and the safety factor of the piers under the central tower was assessed and found to be around 1.8 against general shear failure, but very much less against local failure. This, in turn, allowed alternative underpinning schemes to be evaluated and he provides a comparrison of the five possibilities considered. These were Pali Radice; Pynford stools; ground freezing; Cementation piling, all of which were rejected in favour of an extended concrete pad (raft) foundation solution of sufficient area to reduce the nett contact pressure from about 750 kN/m^2 to the general magnitude, under the walls etc, of 290 kN/m^2. The raft solution eliminated the risk of creating an anomolous "hard spot" by the new foundation which would have occurred if, for example, piles had been used. In order to ensure that the newly enlarged base took up its load with the minimum of additional settlement, a two layer concrete construction was used within which flat jacks were inserted, and pressurised, to transfer load to the new sections of the foundation before it was grouted solid. All this is described in detail, together with measurements of the settlements which occurred throughout the excavation and underpinning operations, (20 - 30mm overall, during the complete, four year project). The settlements accelerated during any removal of overburden which meant that excavation and concreting operations had to be completed as quickly as possible. This is a paper to be read and sets a standard which, I hope, might beneficially influence submissions to the corresponding session at the next I.S.M.F.E. Conference.