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Technical session 4c: Preservation of historic sites

Séances techniques 4c: Préservation de sites historiques

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1 INTRODUCTION

As a general report for session 4c on "Preservation of Historic Sites," the author likes to review the activities of UNESCO as general trend and those of the International Society of Soil Mechanics and Foundation/Geotechnical Engineering on the conservation of old building and historical heritage.

2 UNESCO AND WORLD HERITAGE

In the 1956 UNESCO General Conference in New Delhi still in the aftermath of the Second World War, the proposal to create an integrated an intergovernmental center for the study and improvement of methods of restoration of cultural property was adopted. Following an agreement with the Italian government, the International Center for the Study of the Preservation and Restoration of Cultural Property (ICCROM; ROM stands for ROME) was established in Rome in 1959.

Historic monuments of generations remain to the present day as living witnesses of their age-old traditions. People are becoming more and more conscious of the unity of human values and regard ancient monuments as a common heritage. The common responsibility to safeguard them for future generations is recognized. It is our duty to hand them on in the full richness of their authenticity.

2.1 *The Athens Charter(1931), The Venice Charter(1964), and The Nara Document(1994)*

It was in 1931 when the First International Congress of Architects and Technicians of Historic Monuments in Athens adopted so called "the Athens Charter." Later in 1964, the Second Congress adopted The Venice Charter.

Among the main principles of these Charters, it was agreed that techniques of conservation should be based upon anastylosis(The Athens Charter). Anastylosis is a method of conservation that intends to keep the authenticity of the monuments and will be explained in the later section.

The process of restoration is a highly specialized operation. Its aim is to preserve and reveal the aesthetic and historic value of the monument and is based on respect for original material and authentic documents. Where traditional techniques prove inadequate, the consolidation of a monument can be achieved by the use of any modern technique for conservation and construction, the efficacy of which has been shown by scientific data and proved by experience (The Venice Charter).

Nara Conference on Authenticity in Relation to the World Heritage Convention was held at Nara, Japan, in November 1994 and adopted "The Nara Document" that expanded the authenticity to include any variation of the regional tradition of conservation of heritage. The authenticity means not only the original material or method but also regional practice to continue the monument in the future.

2.2 *Aswan High Dam and Abu Simbel:*

It was in 1960 when Egypt started a very big geotechnical project of the Aswan high dam, and as a consequence the ancient Abu Simbel shrine was to disappear under the dam lake.

Photo-1 Transport to save the monuments, Abu Simbel

The Egyptian Government secured the support of UNESCO and launched a world-wide appeal. During the salvage operation which began in 1964 and continued until 1968, the two temples were dismantled and raised over 60 meters up the sandstone cliff where they had been built more than 3,000 years before.

It was realized that the cultural heritage and the natural heritage are increasingly threatened with destruction not only by the traditional causes of decay, but also by changing social and economic conditions which aggravate the situation with even more formidable phenomena of damage or destruction. THE GENERAL CONFERENCE of the UNESCO meeting in Paris from 17 October to 21 November 1972 adopted an international treaty called the Convention concerning the Protection of the World Cultural and Natural Heritage. The development of geotechnical engineering accelerates the damage and helps the conservation technology as well.

2.3 *Borobudur*

In 1967, Indonesian government requested UNESCO to support the conservation of Borobudur, a very large Buddhist monument in the central Java islands.

The monument is a man made soil mound upon a natural hill with 35m in height and 120m in width. In 1972, UNESCO moved to support the Borobudur restoration work and completed in 1983. In 1975, late Prof.S.Murayama, Kyoto University, received a telegram from Prof.Ambraseys, Imperial College, UK, UNESCO, Paris, being asked to help the conservation project. The slope of the Borobudur monument was anticipated from sliding failure during dismantling phase. Prof.Murayama visited the site and gave advises in geotechnical engineering based upon monitored results(Murayama,1980).

Photo-2 Borobudur monument, Java, Indonesia

3 HISTORICAL OVERVIEW OF ISSMFE/ISSMGE

3.1 *X ISSMFE Stockholm, 1981*

In our society of soil engineering, it was in 1981 at the 10th conference in Stockholm when the theme of historical heritage was granted a session for the first time in its history. The conference venue, Stockholm, was suffering from ground subsidence and the whole city was threatened by sinking under the sea.

The session on "Saving Cities and Old Buildings" was chaired by Prof.J.Kerisel(France) and co-chaired by Prof.A.Croce(Italy). In his introductory speech, Prof.Croce pointed out the specific aspects of pre-existence of structures and large time-scale compared to conventional design problems in soil mechanics in his introductory speaks. He added also two fundamental requirements of cultural aspect of being old and of technical one having an acceptable level of static safety.

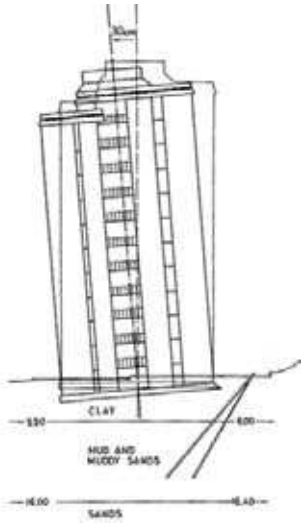

Fig.1 Straightening inclined tower by soil extraction by Vucetic and Djordjevic(1981)

Prof.Croce further spoke of three cities of his own country, Venice, Como, and Milan that are in different geotechnical setting but suffering from the same problem of ground subsidence. Various problems were referred by oral, written, and panel discussion. Among the interesting papers, Vucetic and Djordjevic(1981) reported that extraction of soil under an inclined tower, that was successfully performed in 1978, could be a new method to straighten tall structures.

Prof.Hansbo in his conclusions from the technical session mentioned that the rescue of old cities is the mastering of foundation problems in terms both of technique and economy. The panel of the session concluded several proposals including the collection of case histories for a similar session in the future.

In his conclusions from the technical session, Prof.Hansbo asked the President ISSMFE to send the main documents of the Session 9 "Saving old cities" to UNESCO with proper recommendations.

3.2 *Technical committee organized on Historic Sites*

After the Stockholm conference, the technical committee "Geomechanical aspects of historic sites, monuments, and towns preservation" was established with Prof.J.Kerisel as chairman. From 1985 to 1989, the committee continued as TC-19 "Geotechnical Engineering for Research and Preservation of historic sites, Monuments, and Cities " with Prof.A.Croce as Chairman, Dr.Isnard as Secretary, and Prof.Keriesel as Honorary President under the joint sponsorship of French and Italian Geotechnical Societies. A Symposium on "Engineering Geology as Related to the Study Preservation and Protection of Ancient Works" was organized by the International Association of Engineering Geology(IAEG) and held in Athens in September 1988. Since 1989 to 1994, the Italian society took over the sponsorship of the committee "Preservation of Historical Sites" with Chairman Prof.Jappelli.

3.3 *XIII ICSMFE New Delhi, 1994*

New Delhi Conference in 1994 arranged a discussion session 2.2 on Foundations of Old Structures and Monuments that was chaired by Prof.Habib and co-chaired by Dr.Stamatopoulos.
Prof.Viggiani presented the state of the art report at Session E of Natural Hazard Mitigation on "Mitigation of Natural Hazards Landslides, Subsidence Regional Experiences" including his overview of the preservation of such monuments as Pisa and the Cathedral of Mexico City.

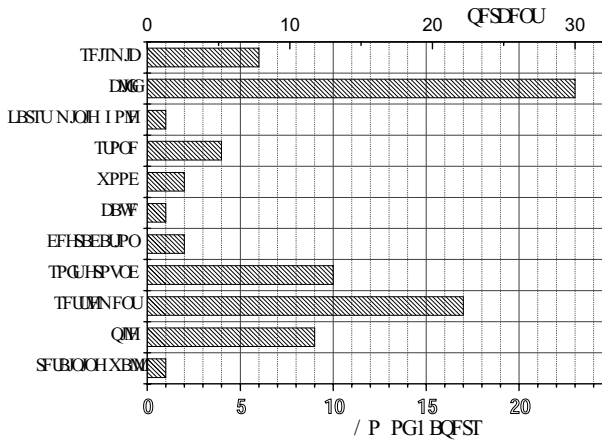

Fig.2 Distribution of subjects submitted to Arrigo Croce Napoli Symposium, 1996

3.4 *ARRIGO CROCE memorial symposium, 1996*

After Prof.A.Croce past away in 1994, a memorial symposium was planned for Arrigo Croce who have developed the integrated approach to the safeguard of monument(Jappelli, 1997). The international symposium "Geotechnical Engineering for the Preservation of Monuments and Historic Sites" was organized by TC19 on Preservation of Historic Sites and held in Napoli in 1996.

Kerisel(1997) gave a masterly lecture on "Geotechnical problems in the Egypt of Pharaohs" dealing with foundation secrets for the Pyramids. Some 100 papers were presented by poster and oral presentation on different problems from various countries. The Symposium was highlighted by a general report on investigation by Smoltczyk(1997) and two state of the art reports on Geotechnical monitoring of historic monument by Burland(1997) and on Monuments and historic sites: Intervention technique by Calabresi(1997).

The nearly 100 papers submitted are categorized on various topics, as it is shown in Fig.1. If we divide their subjects in three categories, i.e. geo-environment, monument itself, and foundation system, geoenvironment and foundation system consist of 90% of the whole number of papers. The problem related with cliff that induces slope instability is the major factor among the geoenvironment category. Settlement and soft ground are the major items in foundation problems.

3.5 *XIV ICSMFE Hamburg in 1997*

An invited lecture " Underexcavation of Mexico City's Metropolitan Cathedral and Sagrario Church" was delivered by E.Tamez, E.Santoyo, and E.Ovando.

They presented the detailed discussion on the soft clay in Mexico city and history of conservation of the Metropolitan Cathedral and adjoining Sagrario Church from controlled piles to the final solution of under-excavation that is removal of the underground soil beneath the foundation to induce settlement of the structures. The differential settlement was about 2.4m.

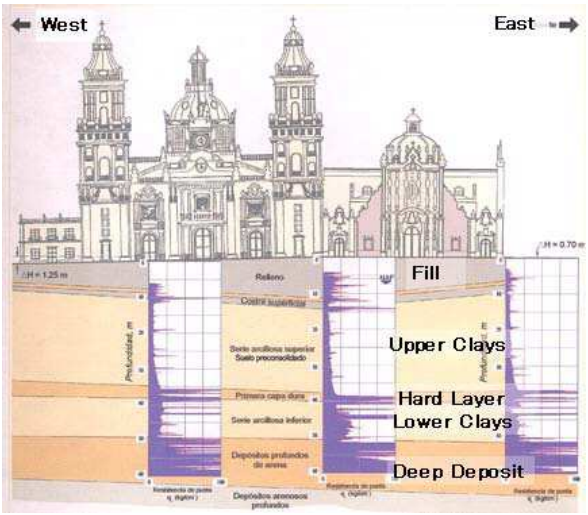

Fig.3 Metropolitan Cathedral and ground condition, Mexico (E.Tamez et al.,1997)

The extraction of soil to rectify the uneven settlement was first proposed for Pisa Tower by Terracina(1962). As mentioned before, Vucetic et al.(1981) was the first to make a report to use this extraction technique to straightening a leaning tall house.

The Terracina's idea was transported to Mexico and were used to level several buildings. The technique is further applied to a smaller church to develop the methodology before applying the Cathedral. The excavation work started from August 1993 and the soil volume excavated reached about 400m3 at 1 April 1997. Heavily instrumented monitoring was performed to achieve the Observational procedure.

The theme lecture by Burland(1997) contains good case histories on the effect of excavation to existing structures.

Photo-3 Underexcavation to extract soil under the Cathedral

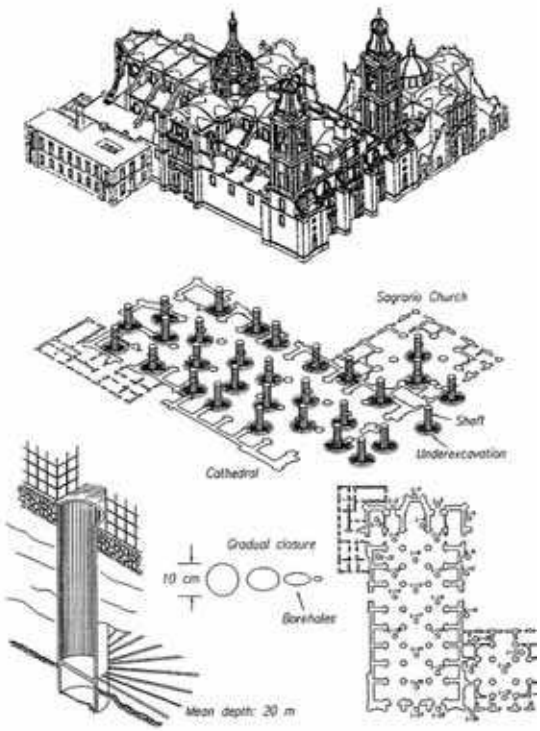

Fig.4 Underexcavation used for the Cathedral, Mexico (Tamez et al.,1997)

3.6 *XV ICSMGE Istanbul 2001*

In the Instanbul Conference, two important lectures were delivered on conservation of historical sites. One is a perspective lecture and another is the Terzaghi Oration.

Ultsky(2001) lectured on his life long work of reconstruction of the city of St.Petersburg as a special Perspective lecture titled "Geotechnical Challenges in Reconstruction of Historical Cities." He showed his experiences of various aspects from grouping damages of piles to application of FEM simulation in St.Petersburg that had been constructed upon very soft ground in 18th century. He also showed some increase of the shear strength of soft soil under the existing foundation. He estimated

strength by vane shear tests with inserting underneath the foundation ground with inclined angles and utilized the result to estimate soil behavior in the future.

Jamiokowski had delivered his Terzaghi Oration under the title "Leaning Tower of Pisa- End of an Odyssey." The whole history of the leaning Pisa Tower was summarized in the paper from the dish shaped depression shape beneath the plinth of the Tower, the maximum settlement of about 3m to monitoring of inclination as well as the comments made by Terzaghi in 1934. The upheaval of the surface of the surrounding soft clay layer in the south side was recognized and estimated as was once very close to bearing capacity failure. The present problem, however, is not the bearing capacity but rather the so called leaning instability of a tall structure upon compressible soil. The inclination of the tower have induced uneven load to the ground that could accelerate the inclination.

In 1990 the Ministry of Public Works decided its closure to the visitors and appointed an International Committee for the Safeguard and Stabilization of the Leaning Tower of Pisa.

It was not an easy way for the Committee to find a solution straight forwards. The intervention of placing lead ingots on the North edge of the plinth was carried out from April 1993 to January 1994. The committee planned to replace the lead ingots with installing ten anchors that are expected to pull the north plinth downwards.

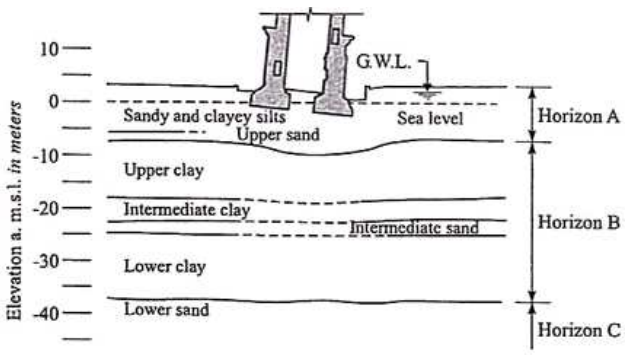

Fig. 5 Ground condition at Pisa Tower(Jamiokowski, 2001)

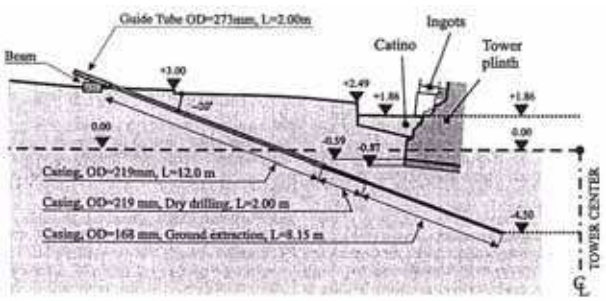

Fig.6 A hole drilled for extracting soil(Jamiokowski, 2001)

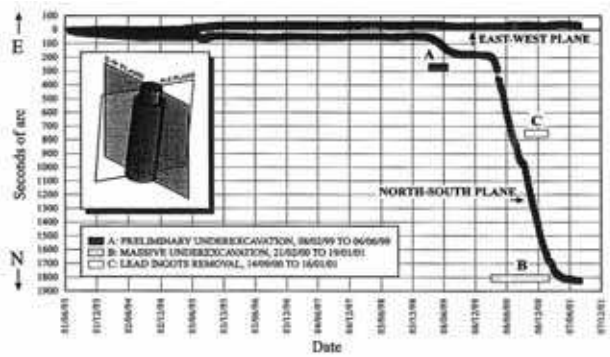

Fig.7 Leaning back by underexcavation (Jamiokowski, 2001)

In the preparatory step, the construction of the prestressed concrete ring for ten anchors, removing small segment of the South Part induced sudden increase of tilting towards south. The Committee had to discard the ten anchors solution. Among three possible interventions of 1.ground water lowering, 2.Electro-osmosis, and 3.soil extraction, the soil extraction became the most reliable method based upon numerical analysis, physical modeling, and a large trial field. The under excavation started on February 1999 as a preliminary intervention and ended June 1999 with extraction of $7m^3$. Tower began to incline northwards with preliminary extraction and continued until the end of the full extraction of the soil with 1800 seconds of arc. It was successful indeed. The paper further describes possible behavior in the future. Three professors, Jamiokowski, Burland, and Viggiani finally reached the another land where they could sleep without nightmare.

The reader may feel the integrated approach that the late Arrigo Croce had aimed at conservation of the monuments.

3.7 *Conference on Reconstruction of Historical Cities and Geotechnical Engineering, St.Petersburg, 2003*

TC-19 and TC-37 ISSMGE, and Russian Society for Soil Mechanics and Geotechnical Engineering organized an international conference dedicated to the tercentenary of St. Petersburg in September 2003. Ten special lectures that cover various geotechnical problems at several sites in the world were presented.. Two sessions were arranged. One is reconstruction of historical cities where 20 papers were presented. Another is geotechnical calculation and soil mechanics. More than 100 participants enjoyed discussions at the very historical house of Architects in Saint Petersburg.

After the conference, TC-19 meeting was held. The committee decided to publish a manual for conservation in geotechnical engineering.

3.8 *XVI ISSMGE Osaka in 2005*

There are six papers that are classified as in the group of Preservation of historic sites to be discussed under a technical session 4c. The papers are reviewed by the author in the later section.

4 ANASTYLOSIS IN GEOTECHNICAL ENGINEERING

4.1 *Preservation Work in Angkor*

The preservation efforts were made early in 1900 by French people by EFEO(Ecole Française d' Extreme-Orient). Structures in danger of collapse were propped and cracks were filled with mortar made of gravel, sand, and mud. The clearance was extended to include canals, Royal Plaza, footpath, and road. In 1925, Angkor Historic Park was officially declared and maintained until 1970s.

4.2 *Anastylosis from Borobudur to Angkor*

In 1929, a Dutch architect, Dr.Van Stein-Callenfiels, visiting Angkor invited French to see his reservation work on Borobudur, Indonesia. The mission returned from the Indonesia, French began in 1931 a new method of conservation known as "Dutch's method" or "Anastylosis."

"Anastylosis" is internationally recognized as a standard method to be applied for the restoration work of historical heritage, which Japanese Safeguarding Team for Angkor(JSA) also recognizes basic principle to restore Angkor monuments.

"Anastylosis" is a Greek word that combines "Ana(re-establish or going back in time) + stylos(column)+is(a suffix to make noun)".

Based upon Balanos, a Greek Architect, who expounded the theory of Anastylosis, Anastylosis consists in the restoration or re-erection of a monument using its own materials and according to the construction methods proper to it. Anastylosis allows the discreet use, where justified, of new materials to replace missing stones in the absence of which it would be impossible to replace the old component. The Dutch was the first to introduce this method in Asia to restore the Borobudur monuments in Indonesia from 1907 to 1911.

4.3 *Application of Anastylosis to Angkor Monument*

The technique was introduced into Angkor and a monument called "Banteay Srey" was restored by the method of "Anastylosis" in 1930's.

Based upon Anastylosis, two major steps have been followed as follows;

1. Cleaning, excavation and plan, search for stones, first attempt for reassembly by lying out on the ground, dismantling of standing sections course by course.
2. Hardening of the ground (with or without a concrete platforms), reassembly with insertion of new stones where necessary (these new components are not sculpted, but roughly hewn, and identified by lead markings) and without using mortar for the facing (the stones to be held in place from behind by iron cramps).

4.4 *Modification of Anastylosis to Angkor Monument*

Though the theory of anastylosis is considered good to keep the authenticity of the original monuments as long as the material is available and the method is possible, it was realized by a French conservator, B.P.Groslier, that there is a poor condition not to be able to support the loads required to bear.

Photo-4 Baphuon temple soil mound pyramid

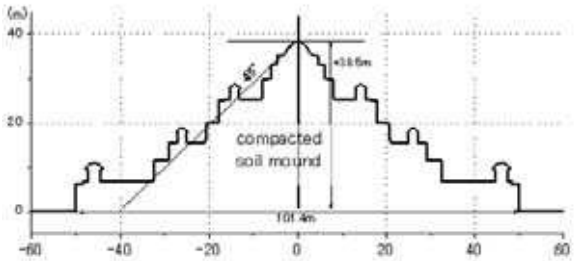

Fig. 8 Section of Baphuon temple, Angkor Thom

If the sandstones or laterite blocks becomes degraded, only putting them back to the original position results in structural failure. To avoid such disasters, it is necessary to add some internal reinforcement or protective measures to counteract mechanical degradation of the structures.

French team had developed and added a new concept to the traditional anastylosis when they began to restore "Baphuon". One of the big problems was how to make the very steep slope of the filled mound. The temple was built upon a man made mound with base length of 107mx132m.

The slope is very steep (40 degrees) with more than 20m in height as shown in Fig.8. In 1950's, they had attempted to restore the steep slope hill by filling up soils, however, the slope failed when the height became about 5m. They tried the filling again, the slope failed again(Dagens,1989, Paskal,1997).

Finally, the French abandoned the anastylosis method of original embankment of filling the mound with only sand.

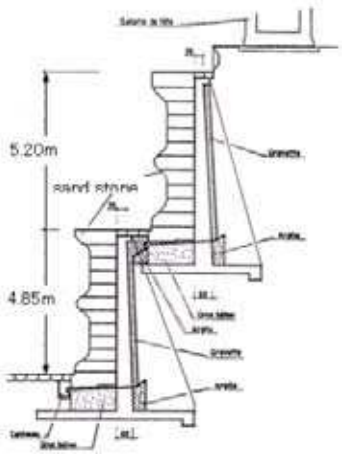

Fig. 9 Adoption of concrete wall at Baphuon temple (Launay, 1994)

Photo-5 Conservation of Baphuon by concrete wall, 2000

They have modified the method introducing reinforced concrete retaining wall inside the slope surface.

Fig.9 shows design section of concrete retaining wall reported by Launay(1994). Photo-5 shows the concrete retaining wall behind the slope surface of decorative sandstones.

Since then French team is used to make concrete retaining wall when the soil mound exceeds about 5m.

4.5 *Foundation mound of Northern Library Bayon*

When Japanese Safeguarding Team for Angkor (JSA) was organized in 1994, it became a big geotechnical issue how to reconstruct the foundation mound that was made from compacted silty sand with a height of 5m. The conservation by JSA was described later in the report. Among such available method of original compacted fill, concrete wall, and compacted fill mixed with some additives, JSA had selected compacted fill mixed with slacked lime. It was obvious that the nearly vertical angle

of slope of mound made by silty sand need some protection in addition to the original surrounding stones.

Compared to concrete retaining wall, the compacted fill mixed with additives was thought more preferable based upon the principle of authenticity. JSA has compared the cement mixed and slacked lime mixed soils based upon laboratory tests. The soil used had the same characteristics regarding the particle size distribution with the soils used in the foundation. The slacked lime mixed soil is weaker but have enough strength and is more stable than cement mixed soil. JSA have selected to use the original soil with slacked lime.

Photo-6 Northern Library, Bayon, Angkor Thom (1994)

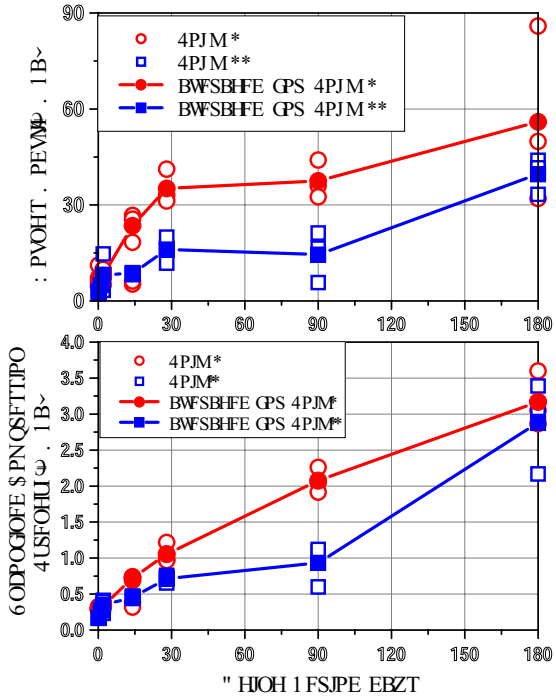

Fig.10 Mechanical Characteristics of Slacked lime mixed soil

4.6 *Leaning Pisa Tower*

In 1970's Italian government called for proposal on consolidation of the Pisa Tower. More than 70 companies submitted tenders. The project was postponed due to shortage of the fund.
The author has no knowledge on the criteria to choose the countermeasures. However, there is no paper, as far as the author have reached, on the discussion of authenticity of the foundation system itself.

In 2003, the TC19 members, in a meeting after the Saint Petersburg Conference, had a chance to evaluate the consolidation methods based upon the concept of the authenticity.
If other type foundations like jet grout, underpinning, or micro piles were adopted, the foundation system became completely different. In this sense, the underexcavation method does not change the foundation system. This method was successful and yet most preferred based upon consideration of the authenticity of the foundation of Pisa Tower.

4.7 *Floating shrine at Hiroshima, Japan*

Itsukushima shrine, Hiroshima, is very old shrine erected in A.D..593. The present structure was constructed in 1168 on the sea.

Photo-7 Replacing rotten wooden footing

The foundation of the structure is wooden footing upon independent stone at the sea bed. The wooden footing stands that in the sea is easily decayed. The rotten footing is regularly replaced by new footing.

This method that does not use the original material does not comply with the original definition of "authenticity" according to the Athens and Venice Charters. However, the expanded authenticity based upon Nara document recognizes that the regional characteristics of conservation method should be respected as the traditional authenticity in regional culture.

5 XVI ICSMGE OSAKA, 2005

The submitted papers dealing with preservation of historical sites are as follows:

- Avellan,et al. "Strengthening the foundation of main building of Tartu University, Estonia"
- Bustamante et al. "The underpinning of a 17th century complex the Montpellier Art Museum"
- Iwasaki "Restoration of foundation of northern library of Bayon"
- Just et al."The restoration of San Pedro cliff at La Alhambra"
- Nishida et al. "Geotechnical characteristics of Japanese catle masonry wall and mechanical analysis for its preservation"
- Ulitsky et al."Analysis of historical building condition with respect to soil structure interaction"

The author has grouped them into two groups; A.case study of geotechnical work for intervention and B. study of mechanism of deformation of old structure and old structure itself. The Group A is applied to the first four papers and the Group B is for the rest papers.

Table-1 and 2 summarize the major factors in each group to discuss.

Table-1 Summary of submitted paper Group A

Author	Avelllan et al.	Bustamante et al.	Justo et al.	Iwasaki
Structure to reserve	Three story building with basement	Montpellier art museum	Alhambra wall-palace	Masonry temple
Site, Country	Estonia		Granada, Spain	Angkor, Cambodia
Time constructed	1632/1807	17th century	14th century	13th century
Upper structure	massive brick			Masonry structure
Type of foundation	stone works upon timber raft+timber pile			compacted mound
Geotechnical condition	soft clay 3-5m thick on very dense gravel layer		tectonically active extension zone steep cliff, opened joints, seepage, erosion 8 cm/year	medium dense silty sand average N=20 W.T.=from GL0 to -5m
State of the object	uneven settlement		being threatened foundation failure due to slope failure	failure of upper structure and deformation of both sides of stair ways
Investigation	archaeological excavation and check cavities		study of old documents, geo-logical, geophysical & geo-technical investigation	geotechnical investigation and archaeological exca-vation
Major causes	decay of wooden raft foun-dation		Active normal faults @ weathering of slope	partial failure of mound

Table-2 Summary of submitted paper Group B

Author	Nishida	Ulitsky	
Structure of Object	Castle wall	Stock exchange	Constantinovsky Palace
Site, Country	Osaka, Japan	St Petersburg, Russia	Strelna, near St Petersburg
Time constructed	1620-1630	1805	1710
Upper structure	With/without castle structure	temple like structure	loggia
Type of foundation	retaining wall	limestone on timber raft	brick work foundation
Geotechnical condition	Maximum wall height = 32m, Base supported by gravel layer (N value > 50)	GL0-3m: soft silty or loose sandy ground Underground water level=GL-1.5m	Soft ground of silty sand, peat, soft sandy clay on hard Cambrian clay
State of the structure	Bulging observed at some loca-tions	Uneven settlement	Fall out of structures
Investigation	Wall shape with stability analysis	condition survey on the foundation	condition survey on the foundation
Mechanism involved	Characteristics of castle stone wall in Japan	no rotting of timber raft no sand washed out	destroyed drainage section under the re-taining structure, Frost penetration, Wash out of soils
Method of Evaluation	3D FEM	3D FEM	3D FEM
Result	Inward curved shape of the wall surface gives much stability at the corner by three dimensional con-fining effect.	computed settlement obtained by the assumed geotechnical condition corresponds well the monitored data.	Analysis to identify the causes of the problem

5.1 *Case Histories*

Avellan et al. present a case history of conservation work for a 200 years old building, Tartu University, Estonia. The building has 3 floors and one basement with dimension of 36m in front width and 11-14m in side width.

The foundation of the building is very thick stone work that was laid upon timber raft supported by timber piles in soft marl clay layer.

The level of underground water went down in the last few decades below the wooden raft level. Due to the drying condition the top of the timber piles became rotten and the building started to settle. The first author investigated the area under the foundation and found that some parts of the wooden raft become completely rotten and left only cavities.

Avellan reports the columns were observed to settle 2-3mm when the intervention work completed in 1996. He refers also that no further movement was observed by the post work monitoring in 1997.

Table 3 comparison of several methods of underpinning

	new woden rafts	grouting	underpinning with jacked pile	minipile
cost	large	small	medium	low
easiness		easy	minimum work space	need machine space
reliability	high	low	high	high
authenticity	the best			

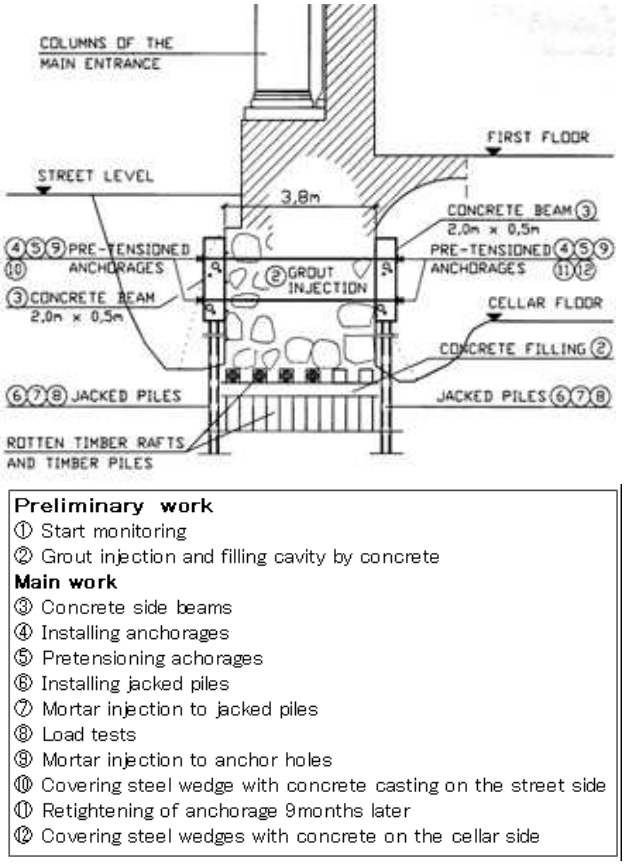

Fig.11 Underpinning by jacked pile and sequence (Avellan, 2005)

Avellan(1996) had also reported another case of underpinning with jacked pile to restore an old church in Estonia.
In Table-3, several methods are compared and evaluated by the author's estimate. Compare to the other available methods, the underpinning with jacked pile is preferred because of several reasons including availability of man power, simplicity, as well as cost

However, as far as the authenticity is concerned, to reconstruction of the original wooden raft pile foundation is the best to preserve the traditional type of the foundation.

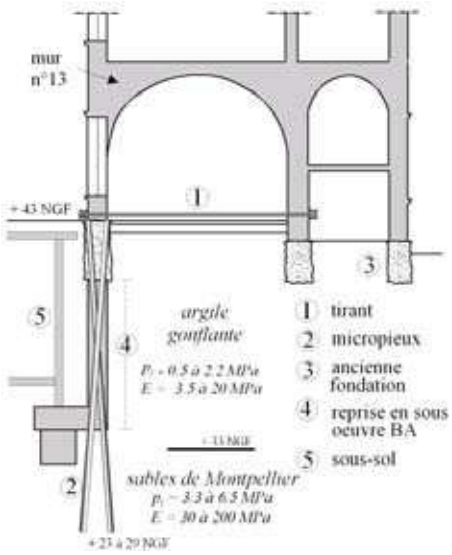

Fig. 12 Micro pile used to create a new basement below the existing structure.

Bustemante et al. report the application of micropiles to replace old concrete foundation with micro-piles for strengthening work of the Montepellier Art Museum. Use of micropiles to strengthen the foundation of an old bridge was also reported by Bustemante et al(1996).

The micropile, which was developed in 1950's in Italy, is a pile with small diameter less than 300mm. There are various kinds of variations and one of the best cost effective solutions to improve the existing foundation system.

Justo et al. present a slope stability problem to safeguard the Alhambra wall-palace that is situated at very short distance 23.8m from the cliff. Alhambra Palace in Granada became a World Heritage in 1993. The Palace stands upon a hill of 65.5m in height. The San Pedro cliff consists of Alhambra formation, upper Pliocene to lower Pleistocene age. In later times of medium and upper Pleistocene, sinking of Granade depression took place.

The tectonics of the region is under extension stress that brought the area normal active faults with strike of NW-SW direction. Small horizontal stress induced many vertical openings and cracks in the slope of the cliff. The average horizontal withdrawal of the cliff is about 8cm/year. It needs about 300years to reach at the foot of the wall. However, it has been a great concern to protect the slope in front of the Alhambra since 1520.

Photo- 8 Alhambra Place and the San Pedro cliff

Among several choices, most of the solutions like heavy slope protection are not selected because of the drastic change of the scenery, which is a part of the authenticity of the region.

Table-4 Comparison of methods to protect San Peddro cliff

	Stop Watering	Grouting	Anchored Wire Mesh	Others
cost				
easiness				
reliability		no		
vegitation	die out			
scenery authenticity			less impact	changes

Anchored wire mesh was selected to protect the slope including the slope instability caused by earthquake. Geotechnical consideration was performed based upon conventional slope stability analysis. The strength parameters are adopted for each geological formation as shown in Fig.2.

One of the authors question is the selection of earthquake for analysis. It was assumed that the life period is assumed as 100years. Is the world heritage of Alhambra worth while no more than 100 years ? The active fault runs very near under the site. What kind and how large magnitude of earthquake is anticipated from the active fault ?

Protection of cultural heritage from earthquake is an important but associated with very difficult decision process.

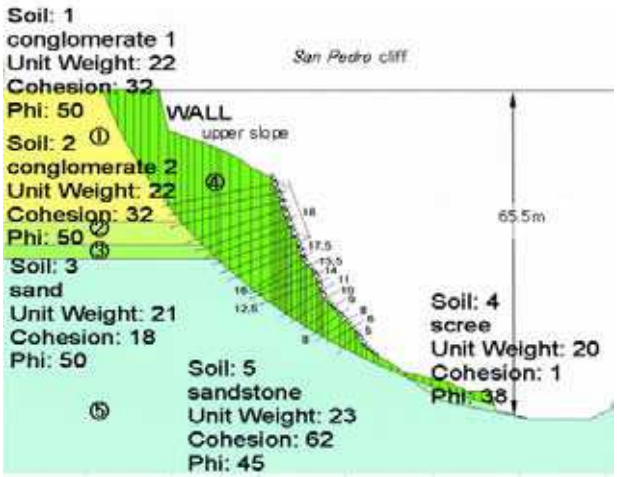

Fig.13 Stability analysis for anchored mesh protection

Iwasaki reports a case history on restoration of masonry structure in Angkor, Cambodia. The Angkor is listed in 1992 as a cultural heritage in danger.

Photo- 9 Northern Library, Bayon in Angkor Thom

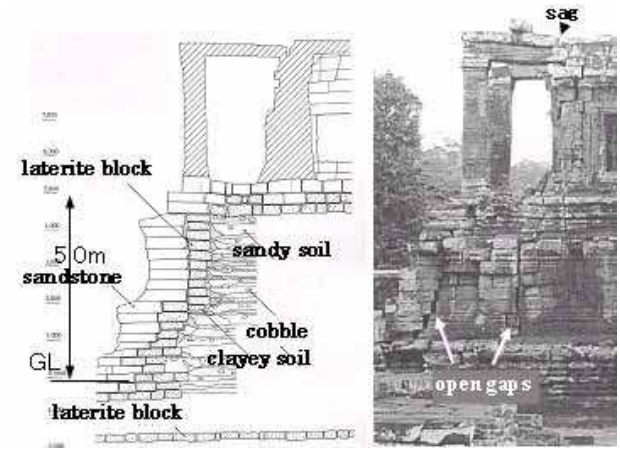

Fig.14 Inside structure of the foundation mound

Japanese government team for safeguarding Angkor(JSA) was organized as an interdisciplinary team under the UNESCO/Japan Trust Fund for the Preservation of the World Cultural Heritage. A case history of northern library, Bayon temple in Angkor Thom that was constructed in 12th century was reported. Structure of the library consists of two parts of foundation and upper masonry structure. The foundation is soil mound of about 5m in height retained by stone blocks 19m in length and 11m in width. The upper structure is masonry porch at both ends and wall with open windows.

The base of the foundation is a well compacted fill that was confirmed to continue down to a few meters from the original ground level. The original ground is medium dense silty sand with an average of N=20 of standard penetration test.

The outer appearance of the foundation shows continuous open cracks that might be caused by sliding of inside mound. However, excavated section revealed no sliding surface in the mound but the decay of laterite block and flow out of the compacted fill. It was estimated that the horizontal move out of the foundation caused by very gentle creep displacement. Infiltration of rainy water into the foundation might have caused the weakening of the surface region of the mound.

Table -5 Comparison of soil mound for Angkor monument

	TPJMNPVOE	DPCDSFUF XBSMI	TPJMNJYFE XJU DFNFOU	TPJMNJYFE XJU TMBDLFE MJNF
DPTU		I JHI		
FBTJOFTT				
SFNBCJMJUZ	RVFTUJPO	ZFT	ZFT	ZFT
BVUI FOUJDJUZ	ZFT	OP		

Among several methods available for conservation, the best method was to build concrete retaining wall inside the foundation.

However, based upon the principle of the authenticity, soil mound is the best solution. However, the reliability of the soil mound is doubtful because of the very steep angle with high height of the mound of 5m. Slacked lime improved soil is much chemically stable than cement mixed soil. Keeping the authenticity of the manmade fill, soil mixed with slacked lime was selected for the reconstruction method of foundation mound.

5.2 *Study of Mechanism and behavior of cultural structures*

Ulitsky et al. present two case studies of old buildings based upon 3D FEM analysis to clarify site specific characteristics as the result of the interaction between ground and structure. It needs to use appropriate modulus of ground as well as the configuration of the soil layers. Before entering analysis, Ulitsky performs site excavation at the existing structure and studies detailed states of structures and foundations as well.

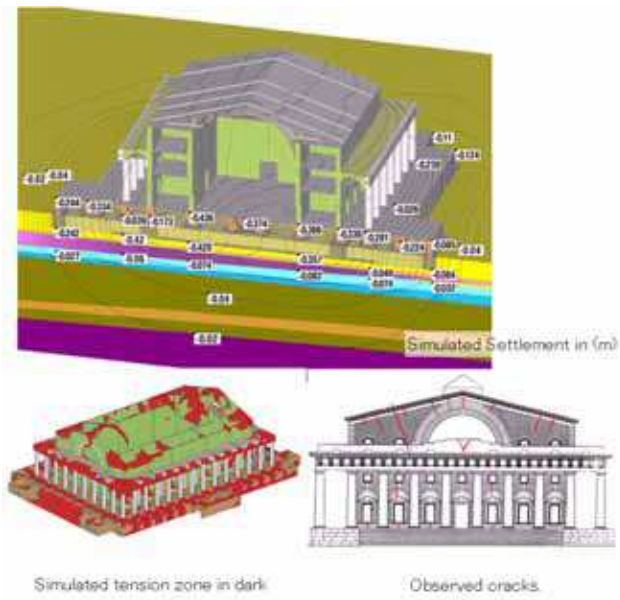

Fig. 15 Contours of subsoil settlements(m) at Stock Exchange building

In the first case of Stock Exchange Building, he found neither rotted wooden raft nor flow out of sand beneath the raft foundation that are the most common cause of the foundation problem.

At Constantinnovsky Palace, in addition to the rotten wooden pile head, foundation of brickwork was weakened by frost action and washout of sand was confirmed.

Knowing these important components related with structural damage, the analysis is performed to explain the states of the deformation as observed. The most important information in the analysis is the mechanical properties like Young's modulus and strength. Ulitsky, who discussed geotechnical parameters in his Perspectives lecture at Istanbul Conference (Ulitsky, 2001),, does not show the detailed process how to estimate these parameters in his paper for Osaka. However, the results presented are based by not only geotechnical but also other structural behavior and show the comprehensive approach that the numerical analysis could explain the mechanism that had caused the structural problems.

Nishida et al. present a detailed analysis on the shape of retaining wall of Osaka Castle. The wall is made of stone blocks. The shape of the slope of Japanese Castle wall is not straight line but concave line along the surface of the wall.

The top of the wall is nearly vertical and it gradually slopes down continuously towards the base. Nishida discusses the inward curved feature of the wall to be very effective to confine the soil ground compared to straight line slope. He confirmed that the presence of the inward curve of the slope and the arch action by the introduction of "*Hiranosuki*" to the wall enhances the wall stability by using 3D FEM analysis. He also notifies the special stone technique "*Sangi-zumi*" in the corner part of the wall to increase the stability.

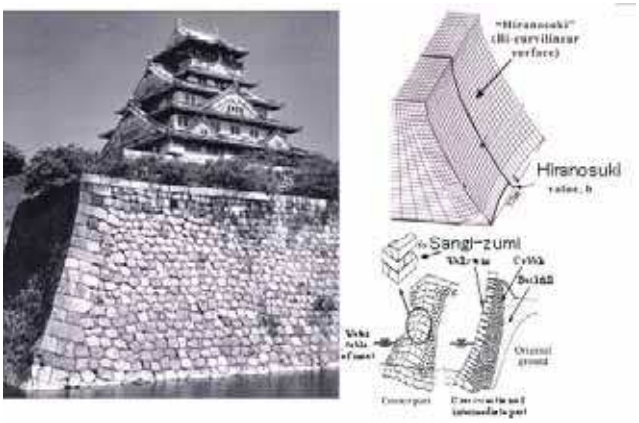

Photo-10 Curved slope of stone wall Fig.16 Osaka Castle, *Sangizum*i and *Hiranosuki*

A field measurement was reported the reconstruction of Marugame Castle wall. Nishida also shows interesting result of bulging data of the stone wall, based on which one can assess the safety of wall failure. The results of these studies provide fundamental data to understand the full mechanism of stone wall of Japanese castles.

6 CONCLUSION

The author has tried to review the conferences of the International Society for Soil mechanics and Geotechnical Engineering as well as general trends of conservation field of UNESCO as a reference.

It turned out that the geotechnical engineers do not have the practice to discuss the consolidation based upon the authenticity of historical foundations.

The author likes to propose to include the one of the important standard to select how to safeguard the monument.

The old monuments attract us not only because they are old or beautiful but also because they present mysterious puzzles that we try to open.

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