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Experiences of geotechnical development in Japan and future directions

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Abstract: Geotechnical engineering (Doshitsu-Koogaku in Japanese) was used since Terzaghi's Erdbaumechanik was translated into Japanese around 1930. The report of the Swedish National Railways about geotechnical engineering was translated into Japanese by the Committee of Geotechnical Engineering, Japanese National Railways, and used as practical reference. The geotechnical engineering was applied effectively for the prevention and restoration of natural disaster and developing food production during 1945-55.

Prof. Noboru Yamaguchi presented a paper to the first International Conference in 1936. The Japanese Society of Soil Mechanics and Foundation Engineering was established in 1950, and have been presenting papers and sending delegates to every International Conference. The Soils and Foundation has been issued since 1960. The 9th International Conference of Soil Mechanics & FE was successfully held in Tokyo. Through these activities, geotechnical development in Japan has been published to other countries in the world.

Before 1965, we learned a lot from other countries. After 1965, the wave of internationalization has advanced remarkably, and it becomes difficult to extract pure advance of geotechnical engineering in this country.

There were many big projects like Seikan Tunnel, Honshu-Shikoku Connecting Bridges, Shinkansen, Highway, Kansai International Airport and Trans-Tokyo-Bay Highway. In connection with these projects, the geotechnical engineering has been developed, and applied to other construction works.

There are many important items to be solved. They are environment, energy and labor saving, cost reduction, maintenance, etc. Innovation is necessary to cope with these future problems. Technology transfer to other countries is also important.

Before 1940

The word DOSHITSU-KOGAKU (soil mechanical engineering, Erdbaumechanik) first appeared in about 1930. Prof. K. Terzaghi wrote the famous textbook, Erdbaumechanik, in 1925. His book was partly translated into Japanese by Dozo Toyama of Nihon University and printed in a civil engineering magazine. The word of Doshitsu-Kogaku was used there. A great earthquake called Kanto Great Earthquake occurred in the Tokyo-Yokohama area in 1923. Many structures, such as levees, road and railway embankments, bridge abutments and piers, dams quay walls were severely damaged. Natural sloped, such as mountainsides, collapsed and mudflows occurred. Reconstruction works were made in a large scale following several years. Toshiki Sano proposed to employ the seismic coefficient for designing earthquake resistant structures after the Nobi Great Earthquake near Nagoya in 1881. Tachu Naito applied the seismic coefficient method for designing a reinforced concrete building of a bank. The building could survive against the Great Kanto Earthquake. This lesson was taken for the earthquake resistant design of buildings in general. Saburo Okabe was a civil engineer at Yokohama Harbor, and in charge of reconstructing quay walls. He tried to use the seismic coefficient method for estimating the earthquake earth pressure against quay walls. He made a simple model test using a handcart, which was used for transporting soil. He tilted the handcart box and measured earth pressure against a plank, which supports the soil in the box. He was invited to work for the Government Civil Engineering Laboratory (now Public Works Research Institute, Ministry of Construction) by Nagaho Mononobe, who was the director of the Laboratory. Okabe moved to the laboratory with other engineers working with him. Haruo Matsuo was a young engineer working under Okabe. Matsuo constructed a vibration table and made a model test of earth pressure in time of earthquake. Mononobe wrote a paper for the Japanese Journal of Civil Engineering and published the book on a method of earthquake resistant design. Earthquake earth pressure was included in his paper and book. This method is Mononobe-Okabe Method, which is used internationally for earthquake resistant design. This method is based on the Coulomb's method, which uses only angle of internal friction. The box shear test apparatus was used to obtain the angle of internal friction. Angle of repose was occasionally used instead of results of shear test.

The First International Conference on Soil Mechanics and Foundation Engineering was held at the Harvard University in 1936. Noboru Yamaguchi, Professor of the Tokyo Imperial University (University of Tokyo), presented his paper there. I heard from Yamaguchi that he had met Terzaghi in Europe. Perhaps this was the reason why he was invited to make a report from Japan, I guess. Here is an abstract of his paper:

Research in Soil Mechanics in Japan substantially started after the Great Earthquake in 1923. At present almost all universities and Higher Technical Schools which have Civil Engineering Departments give instruction on this subject and some of them have special laboratories for this purpose. A few years ago the Government Railway appointed the Geotechnical Committee to investigate the matter on this subject relating to the Government Railway. Laboratory equipments attached this Committee are listed in the following table:

Shear testing machine 11, Apparatus for mechanical analysis 25, Consolidation testing apparatus (Terzaghi's type) 2, Testing machine for direct compression 1, Testing apparatus of model piles 3, Core boring apparatus 3, Foundation prospecting apparatus by seismograph 1, Photoelastic instrument 1, Total area of laboratory 500 m^2, etc.

Subjects presently studied are as follows:

(1) Determination of economical slopes of embankment and cut, measuring internal friction and cohesion of soils by shear test machine.
(2) Determination of economical forms and thickness of lining tunnels.
(3) Studies on economical design of foundations of various structures, especially on weak strata.
(4) Studies on the physical and mechanical properties of soil.
(5) Studies on the geophysical prospecting by electrical and seismic method.
(6) Studies on the pressure distribution under the foundation of various structures.

The shear test machine which was developed by Yamaguchi is a double shear type. Three square boxes, 20cm x 20 cm in section and 5cm in depth, is filled with soil sample. A vertical load is applied from the top, and the middle box is pulled out horizontally by measuring the force. The soil sample is sheared off along two shearing planes. Sand gives upper and lower yield points, whereas clay gives no "drop of beam" phenomenon.

Kamenose Landslide occurred in 1932. This landslide gave rise to a great social problem. If this sliding soil mass had blocked the Yamato River running at the foot of this landslide, the Nara Basin, area of the old capital, would have been filled with floodwater. National Railway and Highway connecting Nara and Osaka were completely interrupted. This landslide was 0.6km^2 in area and 60m in depth. A huge scale investigation was carried out. A lot of boreholes were excavated to take samples and to determine depths of sliding surfaces. Noboru Yamaguchi analyzed this landslide using soil constants, c and ϕ, and determined the depth of the sliding soil mass analytically.

It was 1916 when the quay wall at Gothenburg in Sweden collapsed. Following this catastrophe, a train rolled over down into a lake attacked by a landslide. The Swedish National Railway appointed the Geotechnical Committee to investigate landslides. This committee published a detailed report in Swedish. The Japanese Government Railway Geotechnical Committee translated it into Japanese. This was the best textbook for the Japanese Committee.

Soil science was a part of agriculture and soil mechanics was a small part of applied mechanics before 1930. The Government Railway employed Michitaka Saito, a new graduate, who was a student of Yamaguchi, as researcher in soil mechanics in 1940.

Yamaguchi started research in resistance of a blade against cutting earth. This was the first research work for construction machines using soil mechanics. General trend of research work in the area of soil mechanics was focused to theoretical analysis using differential equations and functions. For instance, Magoji Matsumura (PWRI) solved a differential equation for soil foundation subjecting to a circular bearing plate using a very high order of function. His solution is compared to the solution by H. M. Westergaard. On the other hand, W. S. Housel presented a practical method of estimating relationship between load and settlement.

A kind of soil stabilization method using straw and bamboo was used in old times. Method of mixing soil with lime was used in the 19th Century. Hand tamping was widely used to compact earth for levees and dams. The Proctor method of compaction was introduced, and Kano Hoshino (PWRI) carried out a series of compaction test.

The Civil Engineering Laboratory of the Ministry of Interior (Public Works Research Institute, Ministry of Construction, PWRI) started the triaxial compression test, but did not make any progress.

Method of cut with steep slope was developed to excavate canal through dilluvial formation in Edo (Tokyo). The poor Sendai Clan worked the excavation upon the mandatory order of Tokugawa Shogun. The slope was 20m in height and 70° in inclination. In relation to the construction of castles in plains, the need of constructing high retaining walls with stone facing was essential. The largest retaining walls were located at Edo and Osaka Castles. Method of construction is reasonable from a modern point of view. As their foundation, square lumbers were laid horizontally under the masonry walls. They did not corrode under water. Wooden piles were first driven into the ground for a bridge foundation around 1870. Drop hammer was used to drive piles. Pile formulas were used for estimating ultimate bearing capacity. After the Great Kanto Earthquake, the phneumatic caisson method was introduced from the USA by Tashiro Shiraishi and used for the reconstruction work of the Ryogoku Bridge in Tokyo. The second application of the phneumatic caisson was to the Bandai Bridge in Niigata, which is concrete, multiple span arche. The newly built Showa Bridge fell down, but the Bandai Bridge did not fall down. It well served after the earthquake, and was restored afterward. It is used even now.

In response to the development of industry, large cities like Tokyo and Osaka which are situated on the alluvial strata started to sink owing to the excessive pumping up of ground water. In spite of the Terzaghi's theory, people did not agree with Kiyoo Wadachi, who stated the real cause of ground subsidence in Tokyo and Osaka. Naomi Miyabe analyzed the phenomenon of ground subsidence theoretically and published a book.

As stress was given to railway transportation, roads were terribly bad. It took several days to drive about 500km from Tokyo to Osaka by truck. In this connection, soil mechanics in this area was far behind the world level.

About 80% of the Japan Island is occupied by mountains. Therefore, techniques of excavating tunnels were fairly well developed in this country. Earth pressure cells were used to measure earth pressure against lining systems. Kanmon Strait Railway Tunnel was an entirely new project connecting Mainland Japan and Kyushu Island. Sakuro Murayama was an engineer in charge of the roof shield. This shield engineering technology has been developed extensively, and this method is also used for the Trans-Tokyo bay Highway Tunnel. Two tunnels, 14m in diameter, 20 km in length.

A big typhoon named Muroto Typhoon hit Kobe City in 1938. Mudflow came down from Rokko Mountain behind the city. Restoration works were conducted in a large scale. Soil engineering related to this work has made progress by Shigeru Tanaka et al.

1945 – 55

As the result of 2nd World War, our country was ruined completely, and there were no homes to live in and not enough food to eat. The most important things for us were an increased production of food and energy like coal. Prevention and restoration of natural disasters like earthquakes and floods were indispensable. Following are major disasters in the decade after the war.

Year	Name	Damaged area
1946	Nankai Earthquake	Shikoku, Okayama, Kinki,
1948	Fukui "	Nagoya
1947	Catherine Typhoon	Fukui Prefecture
1948	Aion "	Kanto area including Tokyo
1949	Dela "	Kanto area
"	Kiti "	Kyushu
1950	Jane "	Kanto
"	Kijia "	Kinki
1951	Loose "	Kyushu
		West Japan

Landslides

Chausuyama (~47~), Kamenose (~51~), Soro (52), Ishikura (52), Kiriki (53), Niigata (54), Saseho (54)

Reclamation works as those of the Netherlands were carried out in many places for the purpose of constructing rice fields. Closing embankments were constructed on soft ground. The largest reclamation was Hachirogata Reclamation, the area of which was 20km x 5km. In connection with those big projects, soil mechanics related to soft clay was one of the most important subjects of study. Undisturbed soil sampling, consolidation test, unconfined compression test in a laboratory, test embankment including settlement and sliding were conducted. A detailed report is given in Case History Volume of ICSME, Tokyo in 1977.

Dams for the purpose of irrigation, flood control, and electrical power were constructed extensively. Levees are low dams for flood control. Role of soil engineering became very important to conduct those construction works.

The 2nd and 3rd International Conferences were held from 1945 to 1955. We were not allowed to attend the 2nd International Conference in Rotterdam. But only 4 papers were accepted by courtesy of Mr. Casey, Major General of the US Army. Those papers are:

Takeo Mogami:
1. On the law of friction of sand.
2. Determination of the bearing power of clay foundation

Kano Hoshino:
3. A fundamental theory of plastic deformation and breakage of soil.
4. A practical method of rapid measurement of soil moisture and application.

Papers, No. 1, 2, and 3 are theoretical. They show how much more emphasis engineers put on theory rather than practice. We had a good chance to find that the international trend of soil mechanics was moving toward experiment, field observations, and practice. As our economical condition was terribly bad, it was unavoidable to do small-scale laboratory tests and theoretical researches. Yasumaru Ishii wrote a doctoral thesis on land subsidence in Osaka. It was purely theoretical. He went to Princeton University as a researcher under Prof. Tshebotarioff. He learned a lot from Prof. Tshebotarioff and brought back advanced technology to Japan.

The third International Conference on Soil Mechanics and Foundation Engineering was Held in Switzerland in 1953. A practical paper like "Landslide in Japan by Masami Fukuoka" was selected by the Japanese Committee on Soil Mechanics and Foundation Engineering. This shows the change of our attitude from theory to practice.

Mogami's paper entitled "The Behaviour of Soil during Vibration" referred to "Liquefaction". He made a vibration test with a small-scale apparatus. In his paper: behaviour of sand and loam when subjected to vertical harmonic vibration, the shearing strength of the tested materials diminishes considerably with acceleration of vibration. This effect, called "Liquefaction" by the authors, may explain the behavior of weak soil as observed during earthquakes. Researches into liquefaction have been proceeded by Seed, Ishihara et al. Five delegates attended the 3rd Conference. Tsugio Ohuchi, Matstaro Fujii, Masami Fukuoka, Kano Hoshino and Sakuro Murayama. The National Committee was established in 1949 and approved by the International Society in 1950. It was decided to form 6 regions in the world. Hoshino elected the First Vice President for the Asian Region. After the Conference, Fukuoka visited Sweden and learned Swedish weight sounding, undisturbed soil sampling, rotary foil sampling, cardboard vertical drain etc.

Consulting for soil engineering is very important. Shinsuke Seko started Chuo-Kaihatsu Consultants as early as 1946. Hiroshi Mori established Kisijiban Consultants in 1953. These consultants made soil investigation and applied knowledge of soil engineering to practical sites.

In relation to development of energy, excavation of coal layer under the sea bottom of the Ariake Bay in Kyushu was contemplated in 1948. This sea is famous for being very soft and deep. An artificial island was constructed to excavate a vertical shaft for transporting the excavated coal. Steel mesh was laid on the sea bottom, and sand and gravel were filled on it. The mesh worked on separation and reinforcement. This method is regarded as a kind of reinforcing soil at an early year.

1955- 1965

One of the methods for flood control, which was the main problem of our country, was to increase cross section of river channel, adding surcharge on top of levees. In connection with this work, bridge piers must be extended upward, and girders be lifted up. Earthquake force acting horizontally was increased accordingly. The Yodo River Bridge of Hanshin Railway Company started this kind of work in 1955. The substructure was a group of wooden piles, which had a risk of breakage or had supporting soils broken. Deformation of piles and soils might cause excessive horizontal deformation. Therefore, it was necessary to investigate the mechanism of horizontal reaction of soils against pile. Fukuoka proposed a new method of measuring the relationship between horizontal force and deformation of soil surrounding the pile. Inside a borehole, a rubber tube filled with water was inserted. Then pressure was applied to inflate the tube. A similar method called "pressiometer" was invented in France and introduced to Japan around 1967. Kozo Miki used steel plates instead of rubber tube, and jacks instead of water. This apparatus can be applied to soft rocks, too. As the method of analysis, Y. L. Zhang's formula was used widely.

Economy was improved remarkably during this decade, and large projects of construction began.

Large projects:

1. Roads and toll roads
2. Railways and Shinkansen
3. Bridges crossing sea

4. Dams
5. Harbors
6. Buildings

New method of construction:

1. Sand drain
2. Sand compaction piles
3. Steel piles
4. Cast in place of concrete piles
5. Reinforcing soils using nets and multiple anchors
6. Diaphragm walls
7. Shield
8. Geotextiles

New method of site investigation:

1. Standard penetration test. N-value.
2. Undisturbed soil sampling.
3. Rotary foil sampling.
4. Cone penetration.

Large-scale projects of construction stimulated and accelerated development of geotechnical engineering.

There were two big catastrophes in this decade. Ise Bay Typhoon in 1959 and Niigata Earthquake in '64. New Methods of design and construction were used. At Ise Bay Typhoon about 5,000 people were killed, because sea dikes were broken at many places and 350 km^2 of low land sunk under water. New construction methods were used. Among them, geotextiles were laid under the dike. Niigata earthquake is famous for the large-scale liquefaction. Site investigation and research works were conducted following the disaster. It was proved the vibroflotation piles were effective to prevent liquefaction. Niigata electric power plant was safe in spite of liquefaction, because phneumatic caisson was used, and the building was designed like a ship in sea. Underpinning method was applied to restore many tilted buildings. N-value of the standard penetration method and Swedish weight sounding method were used to find out liquefied saturated sand stratum.

The bullet train called Shinkansen connecting Tokyo and Osaka was completed before the Tokyo Olympic Games. Many concrete buildings and civil engineering works were conducted in Tokyo area. Techniques of soil engineering were developed extensively. Investigation related to the Honshu-Shikoku Connecting Bridges started, and development of new methods of design and construction made progress rapidly. Especially, the method of aseismic design with large-scale model was greatly improved. The newly developed methods were applied to the express way connecting Tokyo and Kobe.

The Japanese Society of Soil Mechanics and Foundation engineering increased its membership, and contributed towards progress of soil engineering. The Journal of Soil Engineering (Tsuchi-to-Kiso in Japanese) was initially published in 1953, and Soil and Foundation (in English) in 1960. Conferences and symposia were held annually. Achievement in geotechnical engineering included in those journals were innumerable.

The First World Conference on Earthquake Engineering was held in Tokyo in 1958. The Second Asian Regional Conference on Soil Mechanics and Foundation Engineering was held in Tokyo in 1959. Those conferences opened the door to participating in international activity.

After 1965

The International Congress on Roads was held in 1967. A section of geotechnical engineering was included. The Chiba Branch of the Public Works Research Institute, Ministry of Construction, was a kind of road research laboratory. A large part of the laboratory was occupied with geotechnical and foundation engineering. Especially, equipments related to the Honshu-Shikoku Suspension Bridges were shown. The Trans-Tokyo Bay Highway and Kansai International Airport are also big projects. Governmental Institutes, Universities, Central Electric Power Laboratory, National Railways Laboratory, etc. expanded their laboratories, a lot of excellent results were reported annually. I cannot cover all of them. Now, I have to write about the 9th International Conference on Soil Mechanics and Foundation Engineering,in Tokyo. The Executive Committee in Moscow voted Tokyo as the next venue of the conference in 1977. There were many problems to be solved. But, at any rate, the Conference was held with great success. Highlight of the Conference was a special lecture by Matsutaro Fujii, President of National Railways, about the Seikan Tunnel. This is the longest undersea railway tunnel in the world. Many new technologies related with tunnels were developed there.

I was elected President of the ISSMFE as an annex. After the Conference, the Japanese Society published the Case History Volume.

Underground tunnels applying the shield method were excavated in cities. Depth of tunnels has become larger and larger using high level techniques. This high level of technology enabled excavation of Tokyo Bay Tunnel, which is 14m in diameter and 10km long. Construction of thirty million-kiloliter crude oil tanks was successfully completed in 1996. The three big national projects, Akashi Strait Suspension Bridge of the Honshu-Shikoku Connecting Bridges, Kansai International Airport and Trans-Tokyo Bay Highway were completed in the 1990's. Experience from these big projects will be applied to other projects in the future. The Hanshin Great Earthquake was the great disaster caused by an earthquake, which strike right under the city. This earthquake gave opportunity to develop new technologies in geotechnical engineering.

Future Development

Japan comprises an archipelago at the end of the Asian Continent, and short of natural resources. She makes a living depending upon import and export. Great part of the land is occupied by mountains, which are composed of collapsible rocks. Typhoons come many times every year and cause great damages. We have to use this land and seacoast most efficiently. Technology to treat soils and rocks, that is geotechnical engineering, is most important for this purpose. Fundamentals of geotechnical engineering should be developed first of all. Construction machineries and materials would be developed as the needs of the case demand. Instruments and techniques of monitoring would also be developed. Geotechnical engineers have to construct various structures for special purposes at different circumstances. For supporting their works, collecting of useful case records and keeping them in good order for easy use are necessary. Accumulating experience is important as well as innovation. Technology transfer to other countries and international collaboration are inevitable.