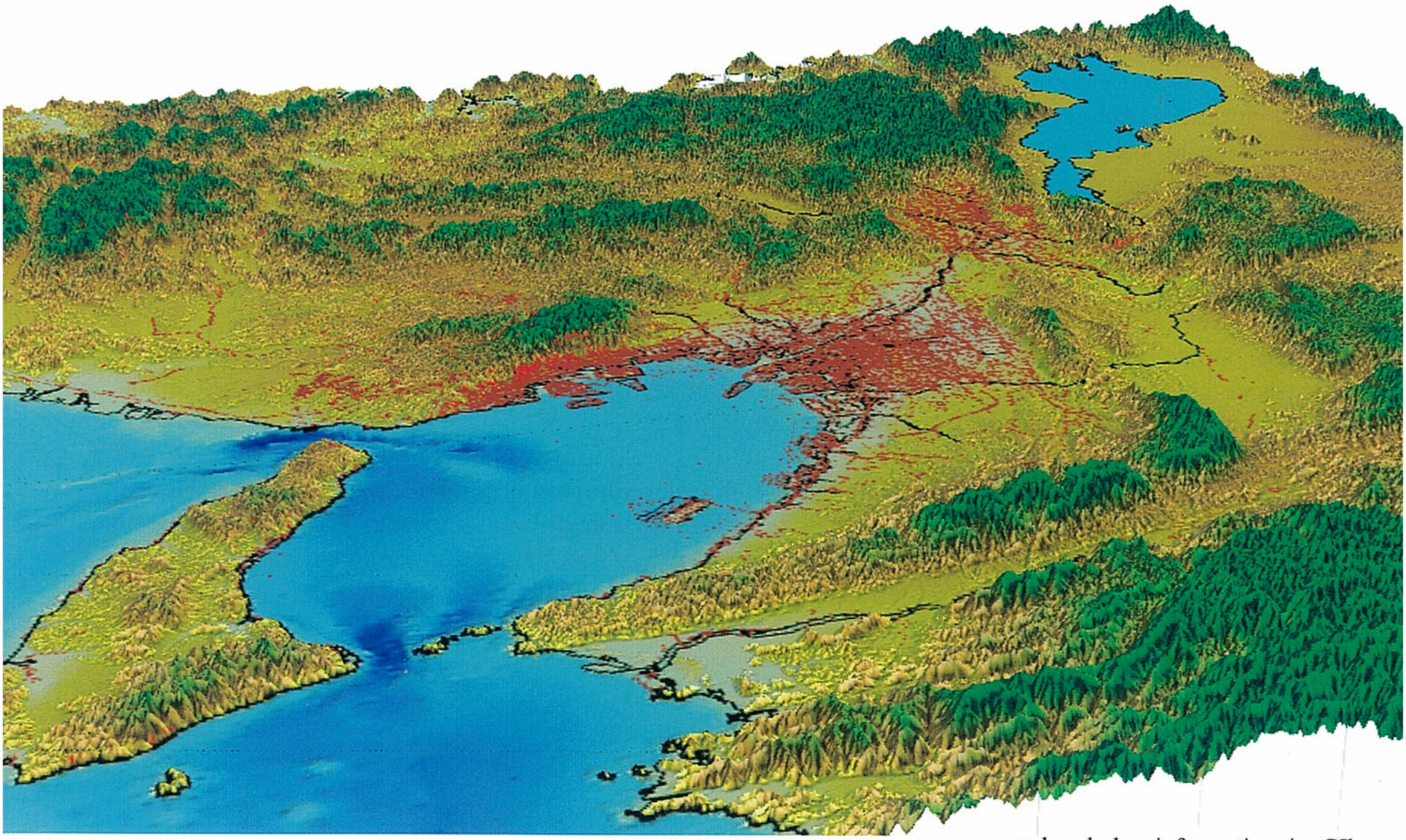
Geo-informatics for Geological & Geotechnical Researches of Kansai Ground



• boreholes information in GIbase

Kansai Geo-informatics Network

KG-NET; **K**ansai **G**eo-informatics **C**ouncil
Kansai **G**eo-informatics **A**gency
Kansai **G**eo-informatics **R**esearch committee

Preface

Today, increased advancements and globalizations in the information technologies are rapidly being realized, and the database technology is one of the fundamentals among these technologies. With respect to the geotechnical engineering, the geo-informatics which deals with a vast amount of geotechnical information in digital forms is rapidly developing in parallel to the advancements in the information technologies. Among the developments of geo-informatics in Japan, "Kansai Geo-informatics Database" (GIbase) would be a forefront runner that has been developing over the past quarter century.

Kansai is a region comprising the second largest economical activities in Japan and therefore a region with active constructions of infrastructures. The region is also known to have many geotechnical problems especially of soft grounds that cover the most of coastal and interior parts of the Osaka Basin. Consequently, many geotechnical advancements have been achieved in this region both in design and construction phases of the technologies. The geo-informatics in Kansai region has developed in parallel to those above geo-engineering practices, but it does not merely means the development of database technology. The development of geo-informatics does consist of not only the technological advancements but also the deepening academic understandings of the ground condition through the geotechnical information. Without the understanding, the database represents a merely huge data container of complex characteristics the nature. We believe that "Kansai Geo-informatics Database" (GIbase) has been developed by satisfying these two requirements both in technology and academic understanding.

Another unique development of "Kansai Geo-informatics Database" (GIbase) stems from its strong alliances with the regional geotechnical research activities. The outcomes from these regional research activities in both geological & geotechnical fields through the use of geo-informatics are returned and fed into the geo-informatics database to refine & upgrade its level of information. For example, the stratigraphic identifications of soils within the borehole data are routinely made by basing on these research outcomes. Additionally, many publications of these research outcomes have been accomplished and these publications form a very important knowledge base for regional geotechnical engineers. Continuous developments and improvements of "Kansai Geo-informatics Database" (GIbase) are made not only in the database itself but also on the management schemes in order to maintain the quality of the database and most importantly to serve for the engineering needs of regional developments. It is hoped that such activities of our geo-informatics will meet the current needs of society.

The publication of this booklet aims to promote similar developments of geo-informatics in many other parts of the world. The management system and its history of "Kansai Geo-informatics Database" (GIbase) is introduced, and then the geological & geotechnical knowledge accumulated so far on the Kansai Ground is presented. We sincerely hope that this booklet would serve as an introduction of many developments in the geo-technologies in Japan.

T. Adachi

T. Matsui

Toshiyuki Adachi
President
KG-C: Kansai Geo-informatics Council

Tamotsu Matsui
Chairperson
KG-R: Kansai Geo-informatics Research Committee

§-1 Kansai Geo-informatics Network

History

"Kansai Geo-informatics Database" (GIbase), which is comprised of over 40,000 borehole data of geotechnical investigation, was developed jointly by cooperation among industrial-government-academic organizations in the Kansai region over the past 20 years. This database is utilized effectively for various engineering activities, such as geological & geotechnical researches of regional grounds, design, constructions, earthquake disaster studies and so on, while maintaining its quality and expanding the data quantity.

Fig.1-1 shows historical developments of Geo-informatics DB in Kansai that is now reorganized as the Kansai Geo-informatics Network (KG-NET). The Kansai region, where the second largest economic metropolitan and old capitals in Japan are located, has developed mainly on low, flat and alluvial plains in the Osaka Basin. Many large cities are developed in the Osaka Plains and in coastal areas of the Osaka Bay where soft grounds are widely spread. Thus the development of these cities required careful site investigations with a very large number of borehole studies to construct much of needed infrastructures, such as underground railway constructions in Osaka around 1930s. Such geotechnical research activities of regional grounds continued since then and the publications of "Osaka Ground" (a collection of soil boring logs) in 1966 and "A New Version of Osaka Ground" in 1987 were made.

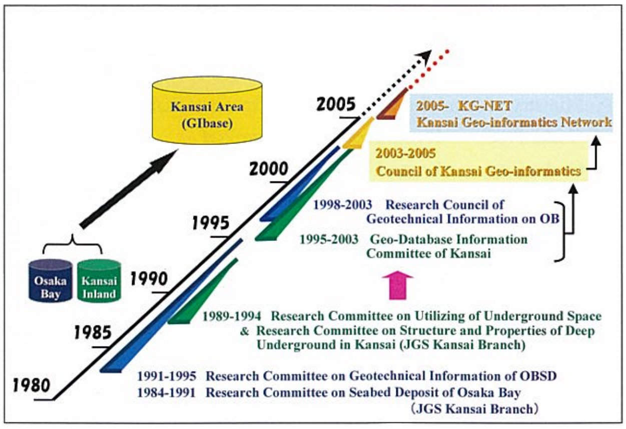


Fig.1-1 History of Geo-informatics Database in Kansai

Borehole investigations for the Kansai International Airport and Phoenix Project (landfills for waste disposals) have started one after another in the Osaka Bay around 1980. Extensive investigations of the Osaka Bay seabed were necessary for the waterfront development, and archiving of data in digital form became routine with the development of computers. The Research Committee on Seabed Deposit of Osaka Bay (1984-1991) was established first by the Kansai Branch of Japanese Geotechnical Society. This activity was succeeded to the Research Committee on GIOBSD (1991-1995) and the Research Council of GIOB (1998-2003). Through these research activities, "Geotechnical Information Databases in Osaka Bay area" (GIbase-OB) was constructed.

On the other hand, the Research Committee on Utilizing of Underground Space (1989-1994) was established in 1989, and this committee dealt mainly with public infrastructures to utilize deep underground spaces in the large city (Osaka, Kobe and Kyoto). This committee work together with the Research Committee on Structure and Properties of Deep Underground in Kansai (JGSKB; 1989-1992). This activity was succeeded to the Geo-Database Information Committee on Kansai (1995-2003). During these research activities, "Geotechnical Information Databases in Kansai Inland" (GIbase-K) was constructed.

These two databases were integrated into a single system in 2003, and the whole data was managed under an organization of the Council of Kansai Geo-informatics (2003-2005). Further in 2005, it is reorganized to form the "Kansai Geo-informatics Network" (KG-NET).

This system is thought to be an ideal form of database management through the experiences gained in the past activities.

Kansai Geo-informatics Network

KG-NET is organized as a new system of management of GIbase in 2005. The objectives of this new system are as follows;

1) Use the database as common property of Kansai,
2) Clarify the roles of participating organizations,
3) Clear & transparent management.

The first objective is to identify the GIbase as a collaborative work of the industrial-government-academic organizations in Kansai region. This was constructed based on the integrated activities lasting over the past quarter century. Moreover, the participations of additional organizations and groups are welcomed and it will strengthen the System in the future by making it as a common property to be shared by the people in construction, engineering research and science fields of Kansai. The second objective is to identify the roles of participating organizations, such as private, public, and academic sectors in the System. The System should be constructed to suit the individual needs of their activity while the organizations expand. The third objective is to establish a transparent management of the integrated networks of organizations in terms of financial accountabilities both in the incomes and expenditures.

In order to achieve these three objectives, the new system of network, KG-NET, is formed by creating three independent organizations as shown in ***Fig.1-2***. Three organizations collaborate through the agreements among them and play their individual roles.

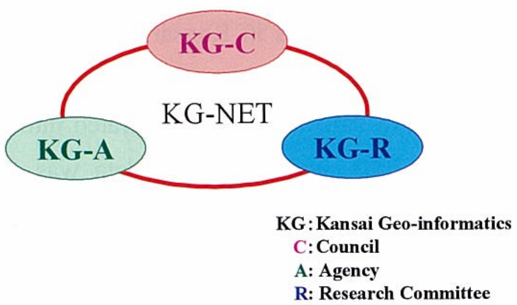


Fig.1-2 Three independent organizations in KG-NET

The outline of each organization is as follows;

◆ **Kansai Geo-informatics Council (KG-C)**

KG-C plays the role as a control tower of KG-NET to promote the Geo-informatics among the various organizations in the Kansai region. This organization is managed by the Ministry of Land, Infrastructure and Transport Kinki Regional Development Bureau. The council members consist of the public sectors, the semi-public sectors such as lifeline companies, and the academics, as shown in ***Table1-1***. In addition, GIbase belongs to KG-C.

- For promotion of the Kansai Geo-informatics
- For support, maintenance and use of GIbase

◆ **Kansai Geo-informatics Agency (KG-A)**

KG-A performs the following tasks for the management of GIbase. Geo-Research Institute is responsible for this work, which involves the member applications of the DB use and management of the GIbase.

- Update and maintenance of GIbase
- Exchanging and offering of database

◆ **Kansai Geo-informatics Research Committee (KG-R)**

KG-R performs geotechnical researches of regional grounds by using GIbase. KG-R is managed by the academics belonging to KG-C, recruits its committee members from the KG-NET members.

- Geological & Geotechnical investigations and research of regional ground by using GIbase

Table1-1 The council members of KG-C

・Ministry of Land, Infrastructure and Transport, Kinki RDB
・Osaka Pref., ・Kyoto Pref., ・Hyogo Pref.
・Osaka City, ・Kyoto City, ・Kobe City
・Japan Highway Public Corp. Kansai
・Hanshin Expressway Public Corp.
・Japan Railway Construction, Transport and Technology Agency, Osaka
・Urban Renaissance Producer, Western Japan
・Osaka Bay Regional Offshore Environmental Improvement Center
・Kansai International Airport Co. Ltd.
・Kansai Electric Power Co. Inc., ・Osaka Gas Co. Inc.
・West Japan Railway Company, ・Kansai Rapid Railway Co. Inc.
・NTT InfraNet Co. Inc., Kansai Branch
・Geo-Research Institute

(as of 2005.8)

§-2 Kansai Geo-informatics Database

Outline

The Kansai Geo-informatics Database (GIbase) was constructed by gathering a very large amount of borehole investigation data obtained in many projects of urban constructions in Kansai region, such as the construction of man-made islands, subways, lifelines, buildings and so on. ***Fig.2-1*** shows the locations of boreholes in GIbase. This database was combined two Geo-databases at 2003, which are the Geotechnical Information Databases in the Osaka Bay area (GIbase-OB) and in the inland area of Kansai (GIbase-K). As described before, the construction of GIbase-OB began in 1987 and the number of input data to the database now reaching to about 4300 boreholes data over the past 20 years, while the construction of GIbase-K started in 1989 with its borehole data reaching to about 38,000. These databases have been utilized for research of geotechnical and geological characteristics in each regional ground, together with practical applications in many projects. Through many research activities based on the databases, many significant findings on geotechnical and geological characteristics have been obtained (Research Committee on SDOB (1990), Research Committee on GIOBSD (1993, 1994, 1995), Research Committee on GOB (2002), and Geo-Database Information Committee of Kansai (1992, 1998, 2002)).

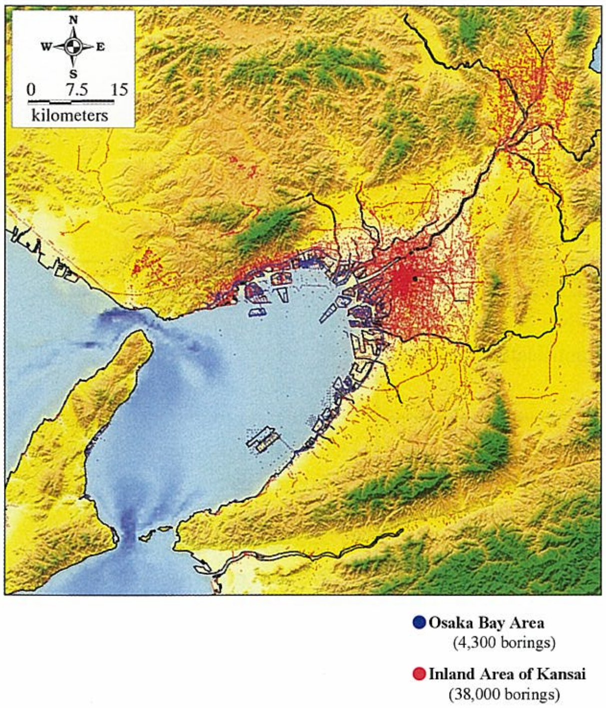


Fig.2-1 Locations of boreholes in the Kansai Geo-informatics Database ; GIbase
(Number of borings is about 42000)

General description of system and input data

The GIbase was constructed by using DIG (Database for Information of Ground) system that was developed by Geo-Research Institute (Yamamoto et al (1989), Iwasaki et al (1990)). The system used for DIG was constructed with a core management system assembling the boring data with its inherent format by extending the concept of relational database. It is composed of the following four functions:

1) Function of total control (Host DB)
2) Function of data input control (Local DB)
3) Function of data extraction and processing (AP)
4) Function of data addition (Layer DB)

The main operation system is controlled by UNIX, whereas the local DB is controlled by WINDOWS. For personal use, the WINDOWS version is prepared for data extraction and processing (AP).

The GIbase includes the detailed contents of investigation reports, so as to provide various geotechnical information to research works. ***Table2-1*** shows the tables (items) of geotechnical input data and their relations in the relational database system.

Functions of the system

The necessary handling skills for managing the Geo-database, DIG consist of five components, such as reference, extraction, processing, analysis and indication. The fundamental functions of DIG are as follows:

1) Indicating the location of each boring on map and selecting the optional ones using mouse operation
2) Referring the boring on optional condition
3) Creating cross-sectional view of the ground by processing selected borings
4) Creating the summarizing table for soil properties and experimental results
5) Processing experimental data and indicating the distribution chart, correlation chart etc.

In addition to such basic functions, DIG also interacts with application programs for the extraction of regional ground characteristics or the examination as liquefaction analysis, etc. DIG also has special function that examines the quality of data by closely looking at the treated data and eliminates unsuitable ones for the purpose of forming data group. It is very important for treating information on the Geo-database.

Geotechnical information of Osaka Bay deposits

Among the input data of GIbase, the borehole data of the Osaka Bay include significantly detailed information. Consequently, the outline of contents of input data at around the Osaka Bay is shown below.

Fig.2-2 shows the variation of number of input borings with year. It is seen from this figure that the boring investigation in the Osaka Bay had been done even in 1956, and that many investigations were carried out between 1970 and 1990. The maximum year of 1982 corresponds to the year in which the investigations of such big projects as the Kansai International Airport were carried out.

Fig.2-3 shows the distribution of drilling depth of boreholes. It is seen from this figure that the drilling depth tends to become deeper as increasing the distances of boring locations from the shore. This means that, as the thickness of the Holocene soft clay layer becomes thicker and the load of reclaimed deposits increases due to the deeper water depth to the offshore, the geotechnical information of deeper Pleistocene clay layer was required.

Fig.2-4 shows the locations of boreholes for undisturbed sampling and various kinds of soil testing. It is noted that the conventional soil testing such as physical properties, unconfined compression, triaxial and consolidation tests were carried out in almost all boreholes. Because thick clay layers are deposited in the seabed of the Osaka Bay, there were several special testing such as a long-term consolidation test but these were performed in limited numbers.

Table2-1 Tables of geotechnical input data and their relations in DIG system

Rank	Level-0	Level-1	Level-2	Level-3
Data table	Root: Area name and related data	Label-1: Data on exploration report and related boreholes	· Label-2: No. of tests … · Strata identification · N-value · Sampling · Rock classification · Rock core quality · Triaxial test on rock · Pressuremeter test · P.S. logging · Reflection logging · Density logging · Electric logging ⋮	· Physical properties tests · Gradation test · Unconfined compression test · Triaxial test · Standard consolidation test · Special type consolidation test · Physical properties of rock ⋮
			Special tests: Long-term consolidation test, Constant strain rate consolidation test, Cyclic triaxial or torsional shear test, Cyclic undrained triaxial test	

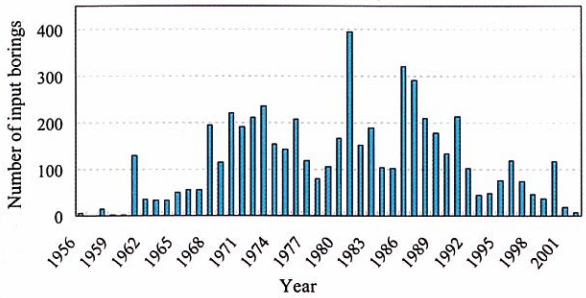


Fig.2-2 Variation of number of input borings with year in Osaka Bay

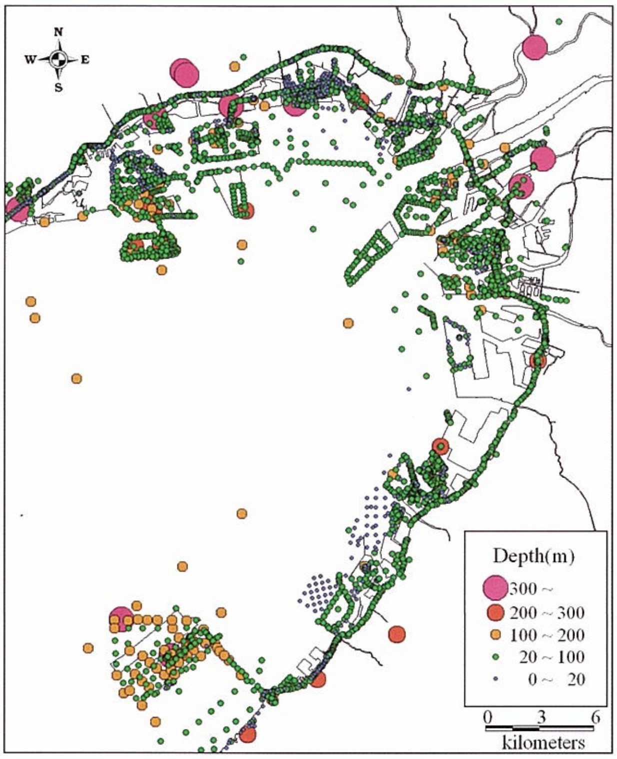


Fig.2-3 Distribution of drilling depth of boreholes

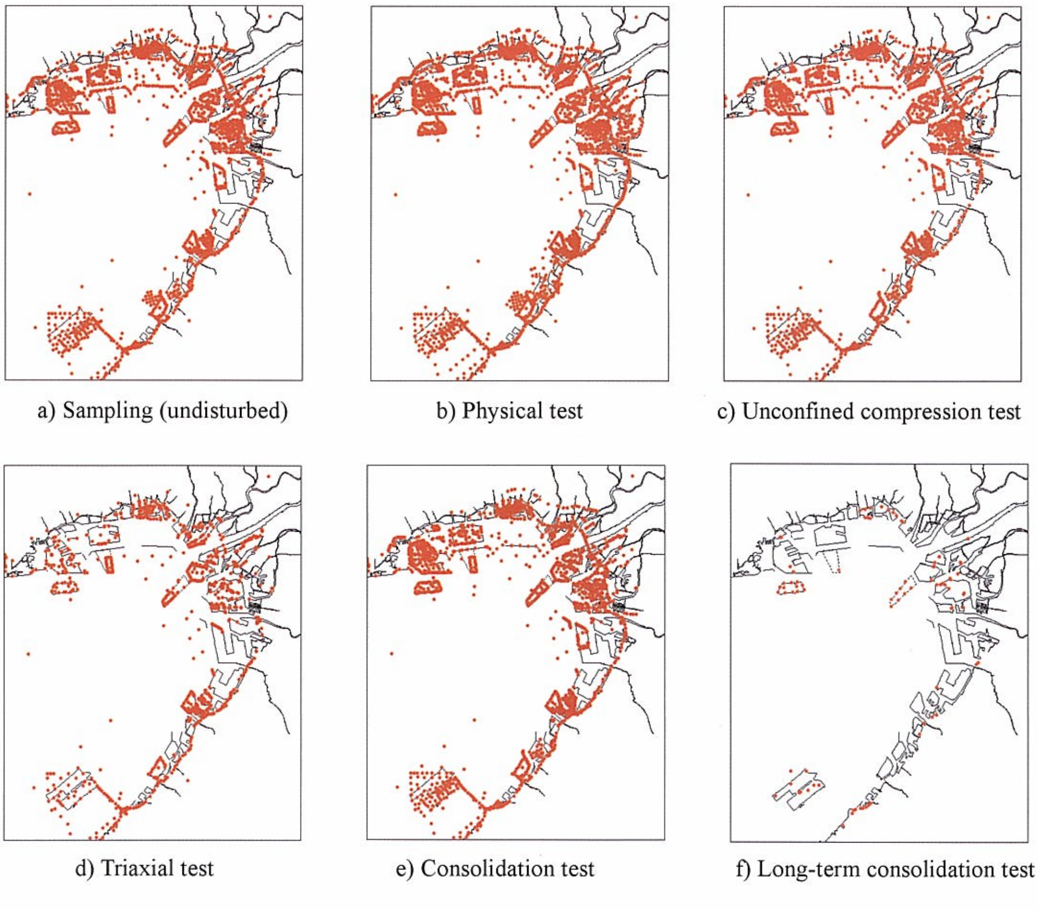


Fig.2-4 Locations of boreholes for sampling and soil testings

§-3 Geological and Geotechnical Characteristics of the Osaka Bay

1. INTRODUCTION

The Osaka Bay, shown in ***Fig.3-1,*** is located at near the center of the Islands of Japan, and it is an inland bay formed in the Osaka Basin surrounded by mountainous regions with bedrock. The present Osaka Bay has an elliptic shape with its long axis in the direction of north-east to south-west. The long axis has about 60km length, while the shorter axis is about 30km. The total area is about 1500km^2. The Osaka Bay seabed consists of multiple layers of marine clay, locally known as Ma13 to Ma-1, that are sandwiched by non-marine layers of sands and gravels. The uppermost Holocene clay layer is called Ma13. These deposits of layers were formed by the depression of the Osaka Basin and the transgression and regression due to the global climate changes repeated in every 100 thousand years or so.

The Kansai area is the second largest economical area in Japan, and the Osaka Bay is surrounded by the cities with high economical and social activities. The development of the Osaka Bay has started from the ancient time, as far back as of the Edo era (1603-1867). Rand reclamation in the estuary of major rivers, such as Yodo and Yamato rivers, had been made for rice field. In the Meiji era (1868-1911), land reclamation along coastal area has rapidly been made for the harbor facilities and industrial sites. After the War, especially after 1965, a trend of land reclamation has changed from that of costal re-development into the construction of near-shore man-made new islands, such as Port Island and Rokko Island in Kobe Port, Yumeshima Island and Maishima Island in Osaka Port, and Kansai International Airport Island located 5km off-shore of Sennan coast. These islands are constructed on multiple layers of very soft to soft and thick seabed deposits with seawater depth of over 10m. Therefore, various types of geotechnical engineering problems are foreseen, for example a large compression of the soft clay deposits, and thus proper

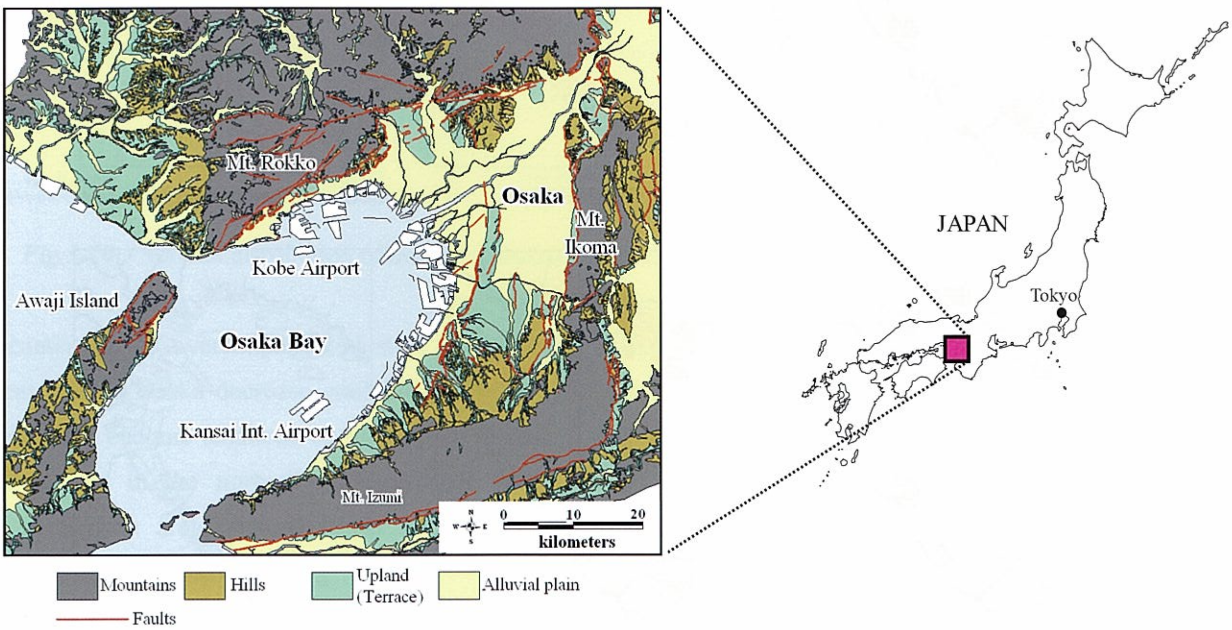


Fig.3-1 Land classification of Osaka Basin (Research Committee on GOB (2002))

geotechnical engineering solutions are sought and examined.

Facing those waterfront developments noted above, it became indispensable for the engineers to understand the geological & geotechnical characteristics of seabed deposits in the Osaka Bay. Thus, the Research Committee on Seabed Deposit of Osaka Bay was established first in 1984 by the Kansai Branch of the Japanese Geotechnical Society, and then it has evolved into the following research committees; Research Committee on SDOB (1990), Research Committee on GIOBSD (1993, 1994, 1995), Research Committee on GOB (2002). The Kansai Geo-informatics Research Committee (Chairman: Professor Tamotsu Matsui) of Kansai Geo-informatics Network has integrated these committees. Research is made in this Committee by utilizing a very large geotechnical database that has been accumulated from many geotechnical projects as note before, and intensive work is made to delineate the geotechnical and geological characteristics of the Kansai Ground, mainly of Osaka Basin that consists of Osaka Plain & Osaka Bay Deposits, using the GIbase.

In this chapter, the geological history of the Osaka Bay is described firstly together with reclamation history. Secondly, the geotechnical characteristics and the regional variations of Holocene clays, Ma13, and Upper Pleistocene clays, Ma12, are described by using several research outcomes of the committees and using the GIbase (Research Committee on GOB (2002)).

2. GEOLOGICAL HISTORY AND FORMATION OF OSAKA BAY DEPOSITS

Histories on geological formation

The Osaka Bay is located in the southwest of the Osaka Basin surrounded by Mt. Rokko, Mt. Ikoma, Mt. Izumi and Awaji Island in the clockwise direction from north (see ***Fig.3-1***). The present Osaka Bay is formed by depression of the Osaka Basin, depositing thick soils layers over one million years or more. The beautiful elliptic shape of the Osaka Bay is a creature that can only be accomplished by nature.

Let us rewind the time of the earth back to 10,000 years ago and look at the Osaka Plains located in the northeast of the present Osaka Bay, tracing the Holocene epoch. Below the Osaka Plains, the marine clay layers including the Holocene clay layer (Ma13) are deposited continuously with those below the present Osaka Bay. This means that the sea area of the present Osaka Bay had expanded in the plain area at the periods of the highest sea level due to the transgression. ***Fig.3-2*** shows the paleotopograghy of the Osaka Plains, in which the transgression and regression in the Holocene epoch (10,000 years to 2,000 years B.P.) were reproduced judging from the marine deposits data. After the final glacial age in about 20,000 years B.P., the sediments of seashore and delta began to deposit at the locations in which the deposits had been eroded until then. In about 7,000 to 8,000 years B.P., the sea water entered along the Yodo river, starting to deposit the Holocene clay layer of Ma13. In about 6,000 years B.P., the sea level reached the highest (the Jyomon Transgression). After then, the regression progressed and the whole Osaka Plains changed again to the land in about 2,000 years B.P.,

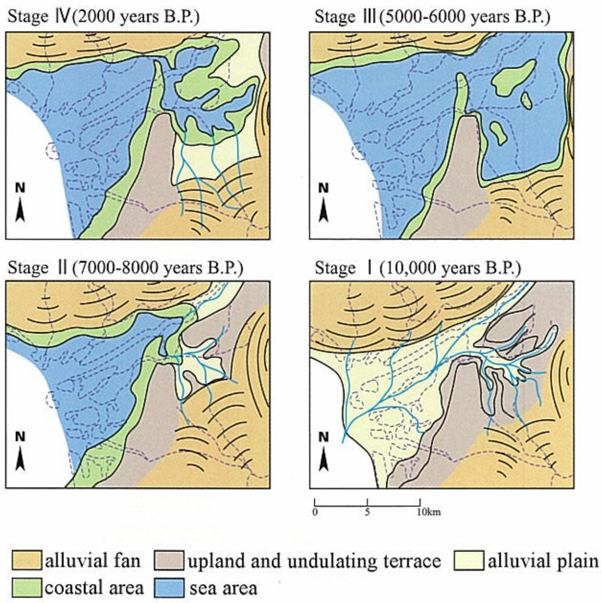


Fig3-2 Paleotopography of Osaka Plains (Mitamura et al (1994))

when the present shape of the Osaka Bay is formed.

The Pleistocene marine clay layers (Ma12 – Ma-1) were deposited in order, sandwiching non-marine layers of sands and gravels, by an almost similar way as in the Holocene marine clay layer (Ma13). That is, they were cyclically deposited by the repeated transgressions and regressions due to the global climate changes (the glacial and interglacial periods) since about one million years ago, accompanying the subsidence of the central part of the Osaka Basin.

Artificial alteration and lands reclamation

The artificial alteration of the Osaka Bay and the Osaka Plains had begun in the Yayoi and Tumulus epochs (about 2,000 to 1,500 years B.P.). ***Fig.3-3*** shows the shorelines and rivers of the Osaka Plains in the Yayoi and Tumulus epochs, in which the vast delta was formed by the regression since the Jyomon Transgression, together with forming many islands at around the coastal area by repeating sedimentation and erosion due to rivers. Since then, the Osaka Plains was occupied by important activities in politics and economics, and then many repair works of rivers and reclamation works were carried out.

At the Edo era (1603-1867), as the Kawachi Plains (eastern part of the Osaka Plains) was changed to the land, the sedimentary soils in rivers directly flowed into the Osaka Bay, followed by expanding the deltas located at mouths of rivers. As the new land development was politically pushed forward, the land reclamation or reclamation by drainage was carried out at around river mouths, artificially forming the present coastal lines along the Osaka Bay.

Fig.3-4 shows the transition of the land reclamation and construction of man-made inlands in the Osaka Bay from the Edo era to date. The reclamation of the Osaka Bay was actively carried out during the Meiji and Taisho eras (1868-1911). That is, in the construction of the Osaka and Kobe Ports, lands for wharfs and port facilities were reclaimed and

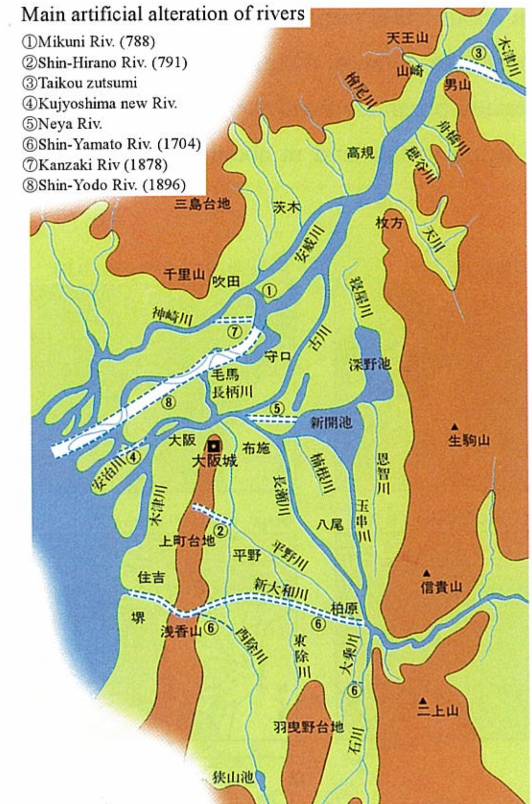


Fig.3-3 Shorelines and rivers of Osaka Plains in Yayoi and Tumulus epochs and artificial alteration of rivers since then (Ichihara et al (1987))

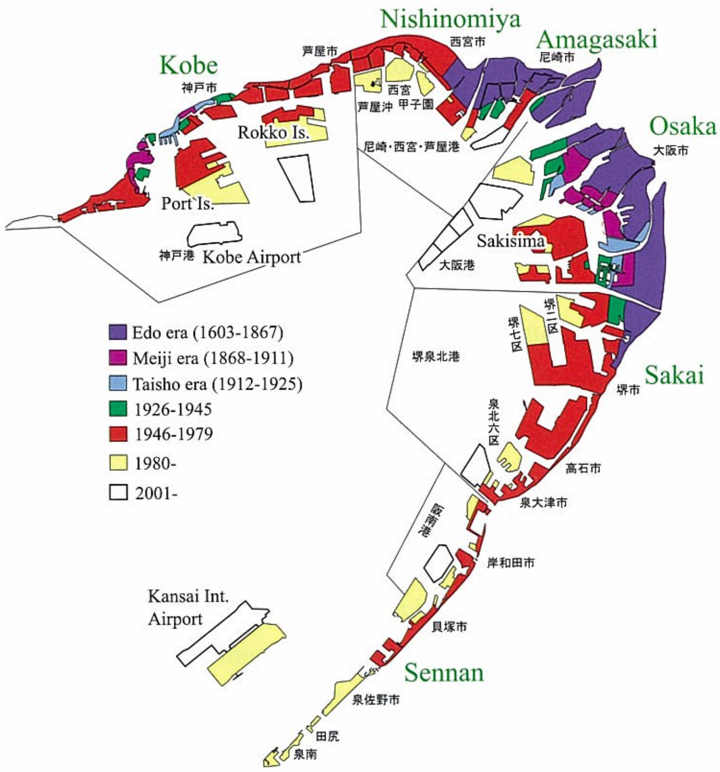


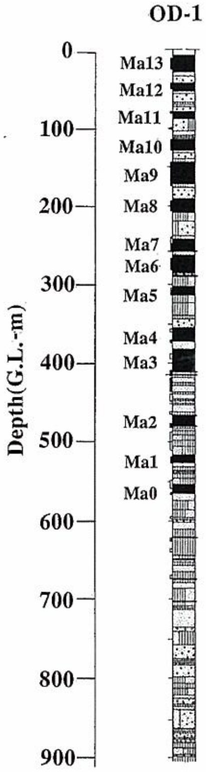
Fig.3-4 Transition of land reclamation and construction of man-made islands along Osaka Bay (Research Committee on GOB (2002))

expanded, together with the industrial and commercial development. Since 1926, the land reclamation was carried out at the surrounding areas (Nishinomiya, Amagasaki and Sakai) near Osaka and Kobe. From about 1955 to 1965, large-scale industrial lands reclamation was carried out, reflecting the high economic growth. After 1965, the construction of offshore cities with overall urban functions was carried out by such reclamation as in the Port Island (Kobe) and the Sakishima Island (Osaka), followed by such large-scale man-made islands as the Kansai International Airport, the Kobe Airport and the Osaka Bay Phoenix Projects. Around the Osaka Bay area, many onshore and offshore projects have been carried out, are in progress or in planning (Matsui (1996)).

Sedimentary layers

Fig.3-5 shows the geological section of the Osaka Basin from Mt. Rokko to Mt. Ikoma, crossing the Osaka Plains. The bedrocks consist of granites, forming a concave structure, in which thick sedimentary layers of the Osaka Groups are deposited. The deepest bedrocks are located at about 1,500m in this section, but it reaches over 3,000m at maximum.

The ground straigraphy of the Osaka Basin may be defined based on the borehole data of OD-1 given at Osaka Port area. ***Fig.3-6*** shows the soil profile of OD-1 and the geological age of marine clay layers. The Quatenary deposits at shallower parts of the Osaka Basin are classified into Holocene layer (Ma13), Upper Pleistocene layer (Ma12, Ma11), Upper Osaka Group (Ma10 – Ma3) and Lower Osaka Group (Ma2 – Ma-1). For these layers, the geological investigation (microfossils analyses of pollen, diatoms, foraminifer and so on) was carried out, followed by giving Ma (marine layer) numbers.



Stratigraphy	Marine clay	Age (ka)
Holocene	Ma13	11
Upper Pleistocene	Ma12	127
	Ma11	242
Osaka Group (Upper)	Ma10	334
	Ma9	427
	Ma8	528
	Ma7	578
	Ma6	621
	Ma5	712
	Ma4	787
	Ma3	865
(Lower)	Ma2	960
	Ma1	1070
	Ma0	1120
	Ma-1	1200

Fig.3-6 Stratigraphy at bore hole OD-1 (Ikebe et al (1970)) and geological age of marine clays

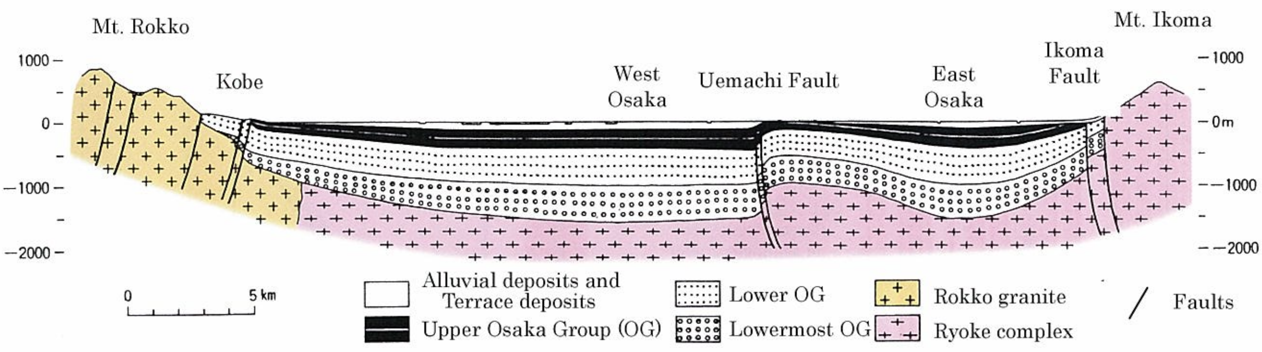


Fig.3-5 Geological Section of Osaka Basin (Ichihara (1993))

3. GEOTECHNICAL AND GEOLOGICAL CHARACTERISTICS OF THE OSAKA BAY DEPOSITS

Outline

The Research Committee of Ground on Osaka Bay has succeeded the research works on seabed deposits in the Osaka Bay in 1998. The Committee has continued & extended the researches on geotechnical and geological characteristics of seabed deposits and geotechnical issues on man-made islands construction in the Osaka Bay, based on large amounts of geotechnical and geological data accumulated in the GIbase.

In this section, the geotechnical characteristics and the regional variations of two dominant marine clays (Ma13 and Ma12) are discussed based on the research outcomes of the Research Committee on Ground of Osaka Bay (2002). Additionally the soil properties of the reclamation materials are introduced.

Stratigraphy of seabed deposits

Fig.3-7 and ***Fig.3-8*** show the stratigraphies of soil deposits along the cross sections on on-coast and off-coast, respectively. As the former section is located almost along the natural shoreline in the Meiji era, the regional characteristics of soils supplied from hinterlands are clearly represented. For example, near the Osaka Port (region II in ***Fig.3-7***), thick Holocene clay layer (Ma13) is available, while at I and III regions in ***Fig.3-7*** there is almost no Ma13 layer. In ***Fig.3-8***, superficial marine clay layer is continuously distributed because of deposits in the sea area.

Fig.3-9 shows the stratigraphy of seabed deposits from the seabed of Osaka Port to the inland of Osaka Plains. It is seen from this figure that the Holocene clay layer (Ma13) was deposited almost horizontally and continuously, raising up its bottom elevation gradually from offshore to inland. Also, the uppermost Pleistocene clay layer (Ma12) was deposited below an

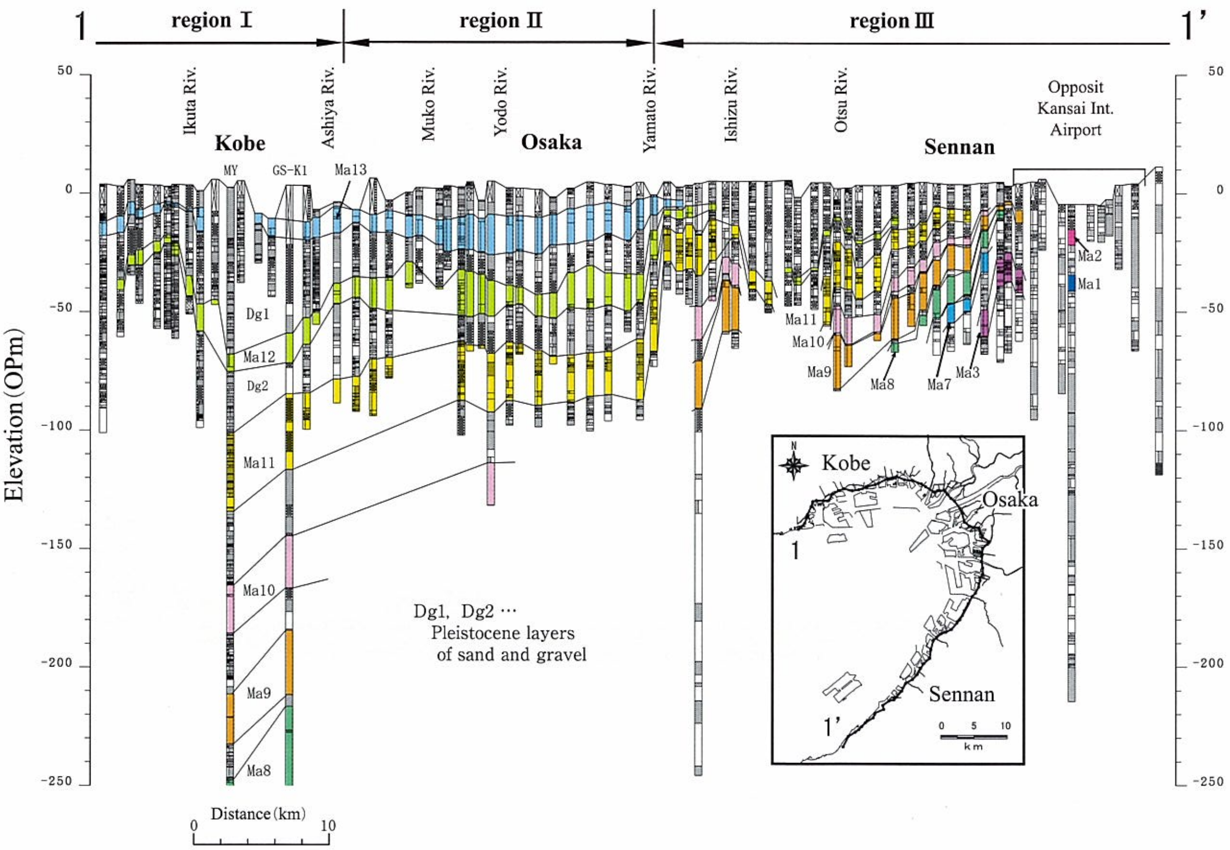


Fig.3-7 Stratigraphy of seabed deposits along a section on shore line

alternating layer of the non-marine clays and the uppermost Pleistocene sands and gravels, which seems to widely distribute below the Ma13 clay layer. The similarity between Ma13 and Ma12 suggests that the depositional environment of Ma12 clay, which was deposited in about 120,000 years ago, was almost the same as in Ma13 clay in the Osaka Bay.

Fig.3-10 shows the variation of the thickness of

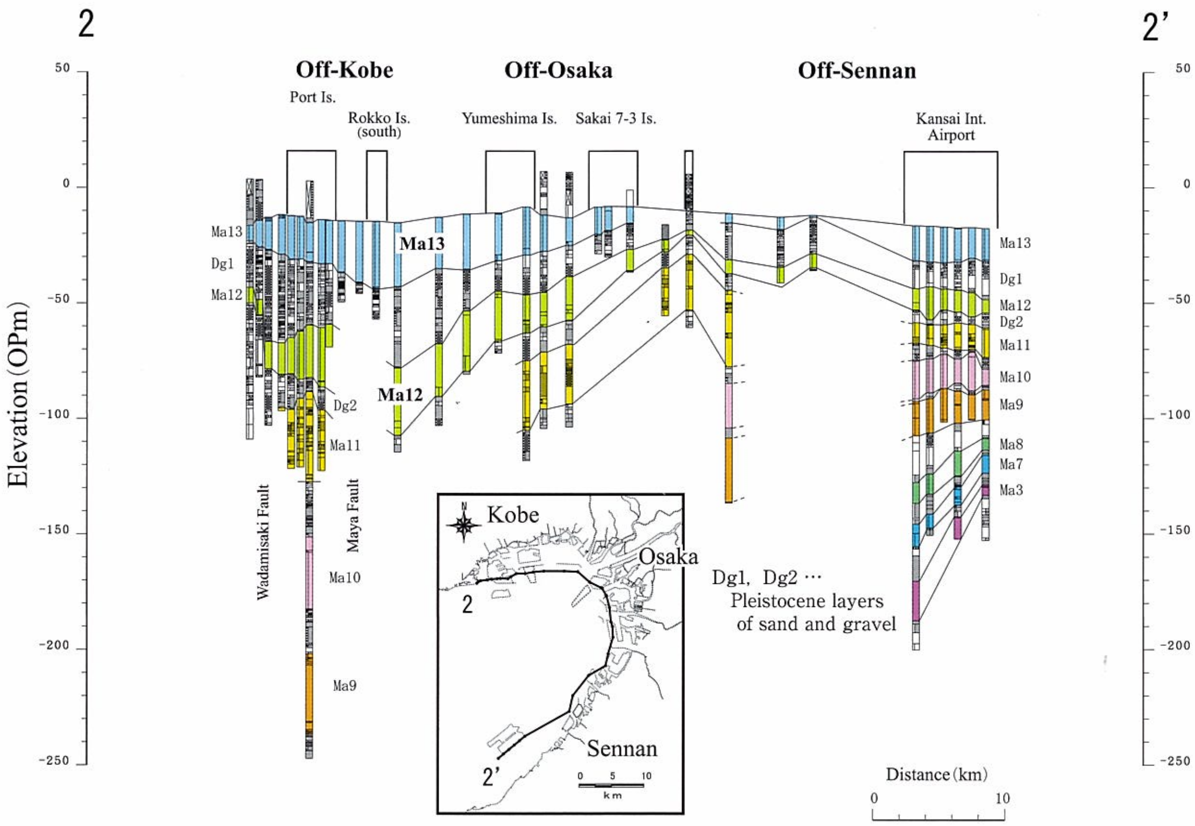


Fig.3-8 Stratigraphy of seabed deposits along a section on offshore

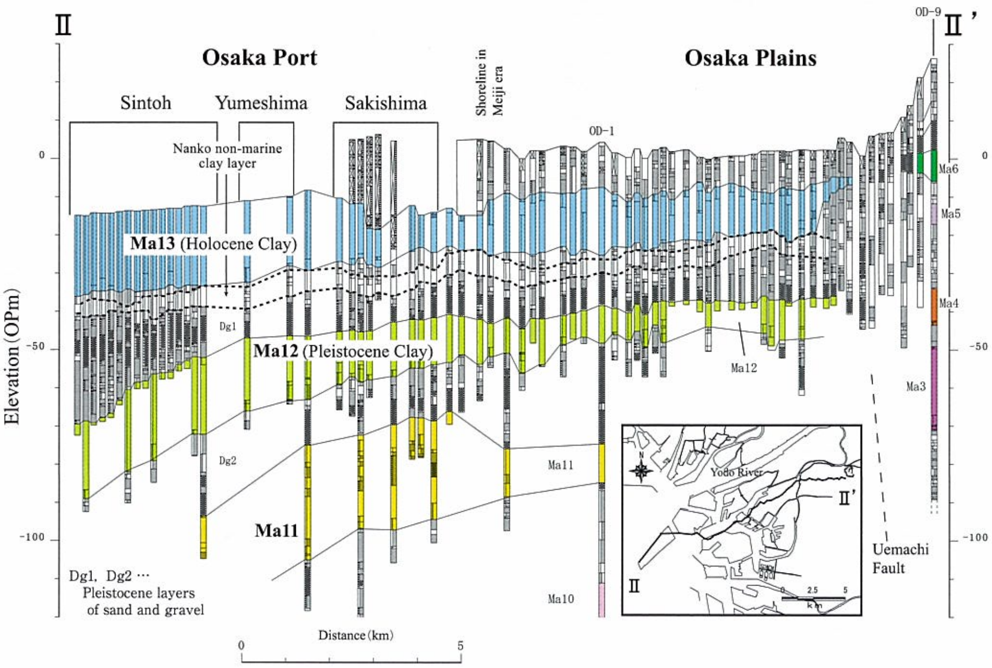


Fig.3-9 Stratigraphy of seabed deposits along a section from Osaka Port to Osaka Plains

Holocene clay layer (Ma13) for each borehole, in which the locations without Ma13 clay (the thickness is 0m) are denoted by "+". Judging from the locations of "+", the distribution boundary of Ma13 clay locates along the natural shorelines in the regions except Osaka area. In other words, the distribution area of Ma13 clay expands to the Osaka Plains behind the northeastern part of the Osaka Bay. This means that the distribution area of Ma13 clay represents the shape of the Osaka Bay at the Jomon Transgression (about 6,000 years B.P.), in which the sea level was several meters higher than the present one, suggesting the depositional environment of Ma13 clay in each location.

Fig.3-11 shows the distribution of thickness of Ma12 clay layer that was deposited at the uppermost part of Pleistocene layers. Judging from the distribution of "+" which denotes "not available", it is noted that the distribution area of Ma12 clay also expands to the Osaka Plains. Comparing with ***Figs. 3-11*** and ***3-12***, the depositional environment of Ma12 clay might be similar as in Ma13 clay, suggesting that the depth of seawater in Ma12 clay is greater than in Ma13 clay, because of the difference of thickness between the two layers. Because the geotechnical characteristics of Ma13 and Ma12 clays are almost similar as will be described later, it could be interpreted from another view point that Ma12 clay had been the clay of Recent Deposit in about 120,000 years ago.

Geotechnical characteristics of Holocene clay (Ma13) and their regional variations

(1) General remarks

The Ma13 clay shows a strong regional variation in soil properties. ***Fig.3-12*** presents the horizontal distribution of geotechnical characteristics (liquid limit: w_L, natural water content: w_n, clay fraction, coefficient of consolidation: c_V) of Ma13 clay along the shoreline from off-Kobe to off-Sennan (Kansai International Airport) through off-Osaka. As for the liquid limit, the smallest value of about 80% appears at off-Kobe, and it gradually increases as moving to

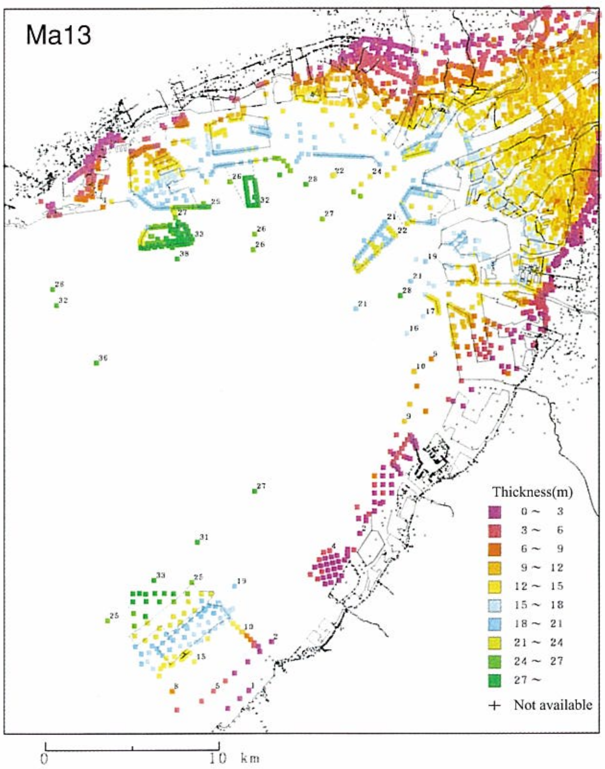


Fig.3-10 Distribution of thickness of Ma13 clay

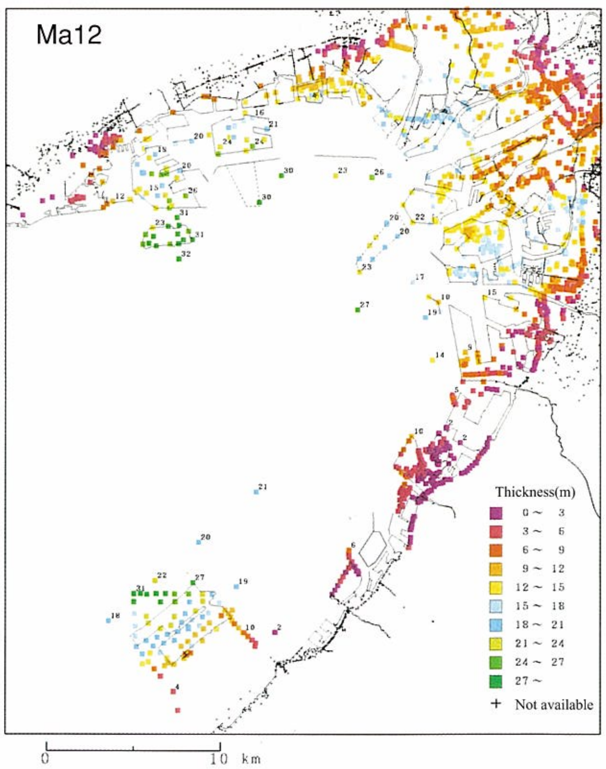


Fig.3-11 Distribution of thickness of Ma12 clay

east, reaching the maximum value of about 110% at off-Osaka. As moving to south, it gradually decreases, reaching about 90% at off-Sennan. This trend is almost the same in the natural water content. As for the clay fraction and the c_V,, their distributions show a trend as about 45, 70 and 50% for the former, and about 100, 40, 90cm^2/day for the c_V from Kobe to Sennan areas in a similar fashion as of the liquid limit.

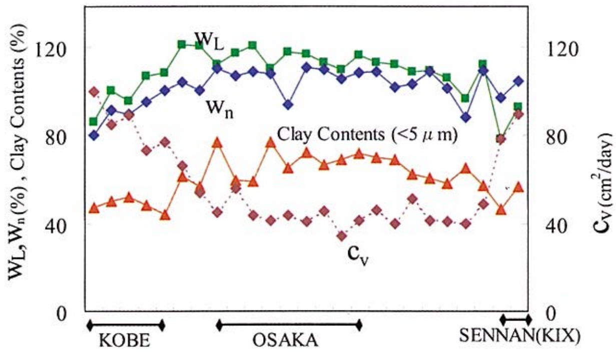
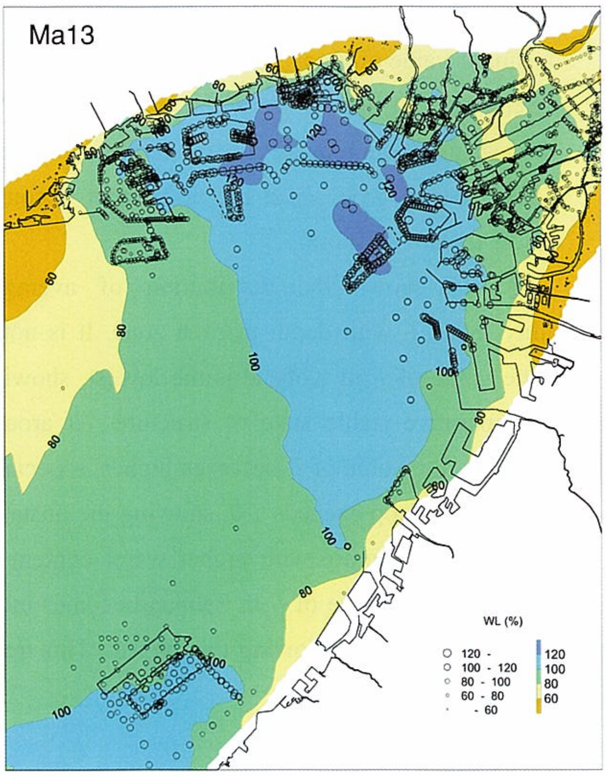


Fig.3-12 Horizontal distribution of soil properties of Ma13 clay

These findings can be seen clearly in ***Fig.3-13***, which shows the contour map of liquid limit for the part of mid depth of Ma13 clay. Also concerning Ma12 clay which is Pleistocene clay depositing below Ma13 clay, it can be seen the similar distribution for Ma13 clay, as shown in ***Fig.3-14***.

As above-mentioned, the geotechnical characteristics of Osaka Bay Holocene clays (Ma13) have significant variations among three regions of off-Kobe, off-Osaka and off-Sennan. These are called "Kobe-type", "Osaka-type" and "Sennan-type" (Nakaseko et al (1987)). The vertical distributions of the liquid limit in these three types have the following features. The details will be described later.

1) Kobe type: constant vertical distribution
2) Osaka type: bow shaped vertical distribution with the maximum at the center of layer
3) Sennan type: decreasing vertical distribution with depth



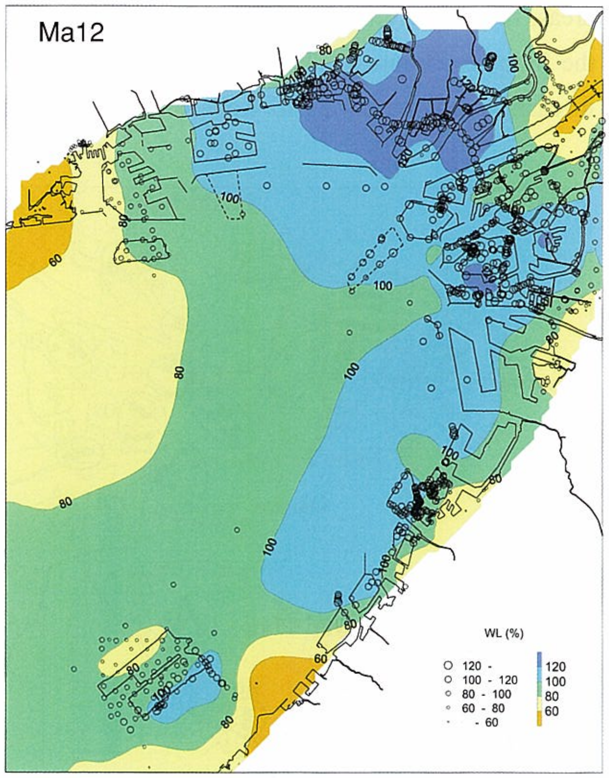


Fig.3-13 Distribution of liquid limit in Ma13 clay ***Fig.3-14*** Distribution of liquid limit in Ma12 clay

(These figures show the contour map of averaged liquid limit of the each clay layer for the part of mid depth, 60% of the thickness. And the circles show the boreholes location and its sizes denote the largeness of liquid limit of clay layer at each borehole.)

As such regional difference of geotechnical characteristics continuously changes, the Osaka Bay area along Kobe to Sennan is divided into such 24 zones in 6 areas as shown in ***Fig.3-15***. These zones can be classified into such three kinds of locations as coastal area including land area, near-shore area and off-shore area. The soil properties in each zone are compared each other, based on boring data in the GIbase. The regional differences of each geotechnical characteristics are discussed below.

(2) Physical properties

The liquid limit w_L and the liquid index I_L are effective as an index representing geotechnical characteristics of Osaka Bay clays. ***Fig.3-16*** shows the vertical distribution of averaged liquid limit of Ma13 in each zone. ***Figs.3-16*** (a) to (e) correspond to 6 areas, where the data are grouped into 2 to 5 zones in each, and the data are shown in three different symbols; half open, fully open and solid marks corresponding to the coastal, near-shore and off-shore areas, respectively (the same classification is used in the following figures). The vertical distribution of w_L in each area corresponds to Kobe, Osaka or Sennan

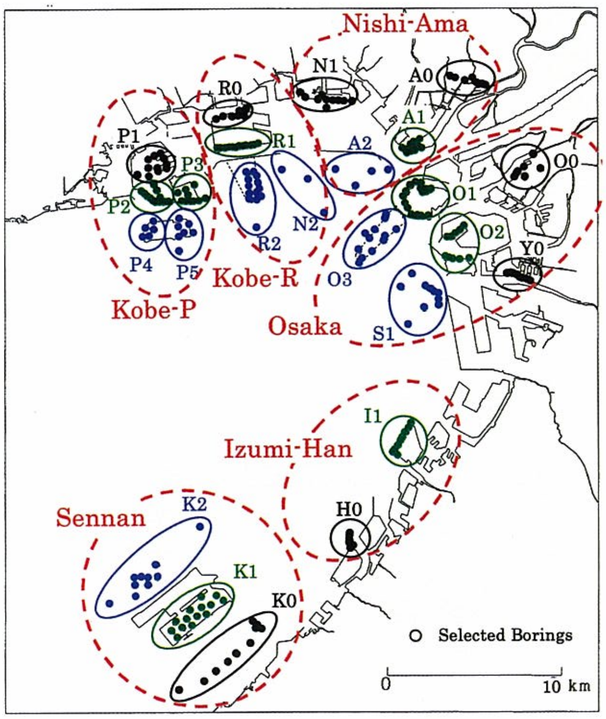


Fig.3-15 Division of 24 zones in 6 areas

type as mentioned-above, while the value of w_L distribution in each zone differs continuously as follows:

1) Kobe P: w_L is about 80-100%, the lowest among 6 areas. All zones show Kobe type. As for the variation toward offshore, similar in the direction of northwest to southeast, and the eastern part is higher.
2) Kobe R: w_L is more than 100%, constant until about 15m deep, under which decreases gradually. The variation toward offshore is similar as in Kobe P.
3) Nishinomiya-Amagasaki: w_L distribution is bow-shaped with about 120% of w_L at the center of layer. All zones show Osaka type. The variation toward offshore is similar as in Kobe P.
4) Osaka: w_L distribution is typical bow-shaped Osaka type. w_L in land area is lower, increasing toward offshore. The distribution shape of O3 at offshore is similar to N2 and A2 in the direction of northwest to southeast.
5) Izumiotsu-Hannan: The clay layer is thin, showing a similar value of w_L as in Sennan.
6) Sennan: The uppermost w_L is more than 100%, decreasing monotonically with depth. All zones show Sennan type. w_L at the upper part becomes lower toward offshore.

Fig.3-17 shows the distribution of averaged lquidity index I_L with depth in each zone. It is noted that the value of I_L in Kobe P is the lowest, showing the comparative stable state of structure. At around Osaka area, the value of I_L becomes higher, especially the value at the top exceeds 1.0, showing the unstable (soft) state of structure with higher water content of clays. While, the value of I_L in Sennan becomes more than 1.0 in some part, showing the highest. This trend is different from that in w_L.

(3) Consolidation and strength characteristics

The Osaka Bay Holocene clay (Ma13) is regionally different in the consolidation and strength characteristics as well as in the physical properties. Judging from

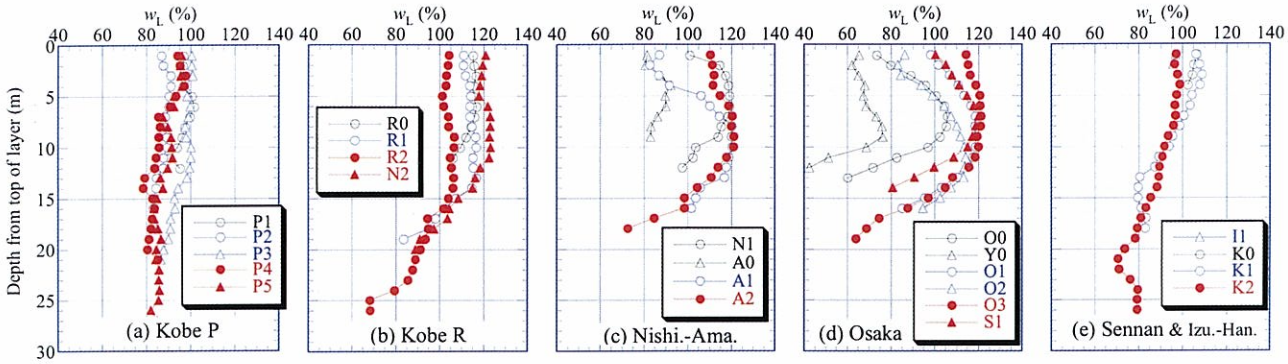


Fig.3-16 Vertical distribution of averaged liquid limit of each zone in 6 areas (Ma13)

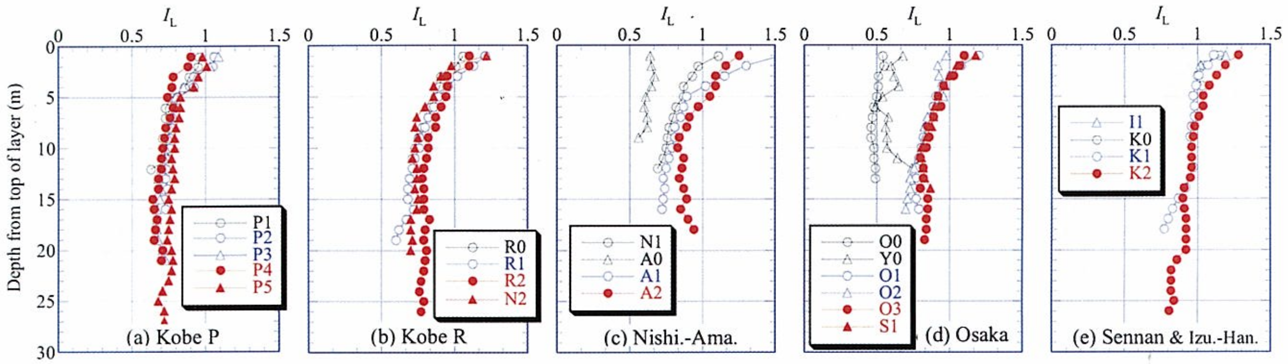


Fig.3-17 Vertical distribution of averaged liquidity index of each zone in 6 areas (Ma13)

the distribution of Ma13 clay as shown in ***Fig.3-10***, it can be estimated that the area around the Osaka Port was significantly influenced by the transgression and regression, while the areas of Kobe and Sennan was not. Further discussions on the regional variation of geotechnical characteristics are necessary, for example, on the reason why the Holocene clay in Kobe area are lightly over-consolidated. Therefore, such regional differences of the compression curve, consolidation yield stress and unconfined compressive strength are discussed below.

Fig.3-18 shows the representative compression curves of each zone in 6 areas, the data points of which are obtained as the mean values of data between top of clay layer and location of 7-9m deep. The compression curves are located at the lowest position in Kobe P area, moving upward in the areas toward Osaka or offshore, then moving downward again in Sennan area. The shape of curves in the normally consolidated part is almost linear in Kobe P area, while concave in the areas toward Osaka. All curves tend to converge as increasing the consolidation pressure. In each figure, the standard compression curve from initial void ratio e_0 (SCC(e_0=1.5e_L) in which e_L is the void ratio at w_L) by Tsuchida (2001) is also shown based on the mean value of w_L. As the value of w_L in each zone is not necessarily the same, the curves in each area scatter a bit. The curves are located a little below SCC in Kobe P area, almost on SCC in the areas toward Osaka, and a little above SCC in Sennan area.

Fig.3-19 shows the vertical distribution of averaged consolidation yield stress p_c of each zone in 6 areas, in which the dotted lines signify the effective overburden pressure p_0. The p_c in each zone increases almost linearly with depth, having a little bit concave trend. The values of p_c in Kobe P area are largest among 6 areas, being located above the p_0-line

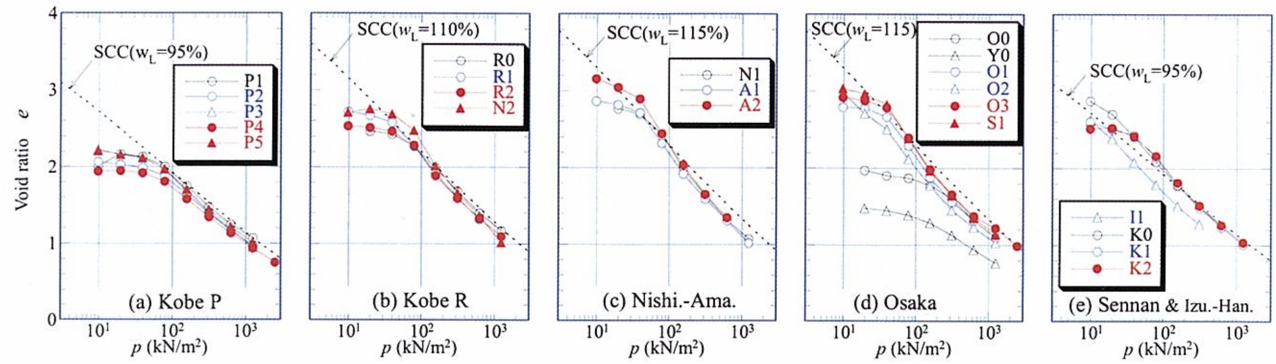


Fig.3-18 Representative compression curves of each zone in 6 areas (Ma13)

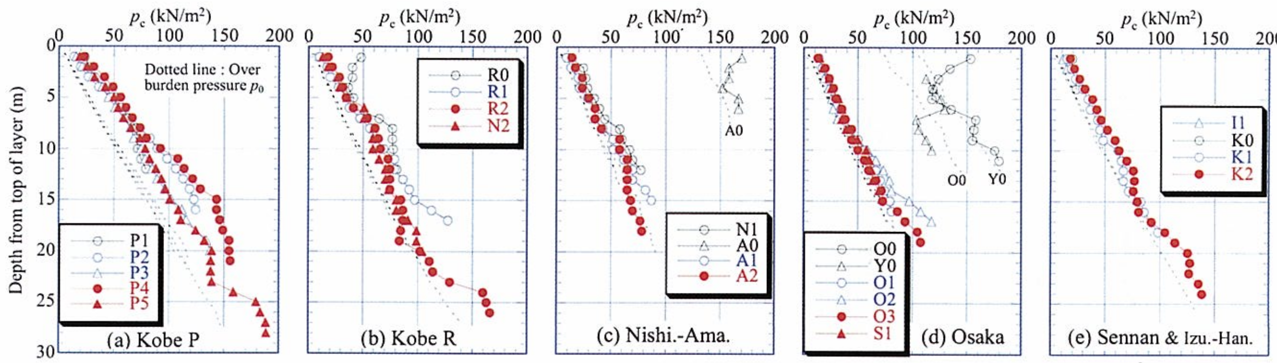


Fig.3-19 Vertical distribution of averaged consolidation yield stress of each zone in 6 areas (Ma13)

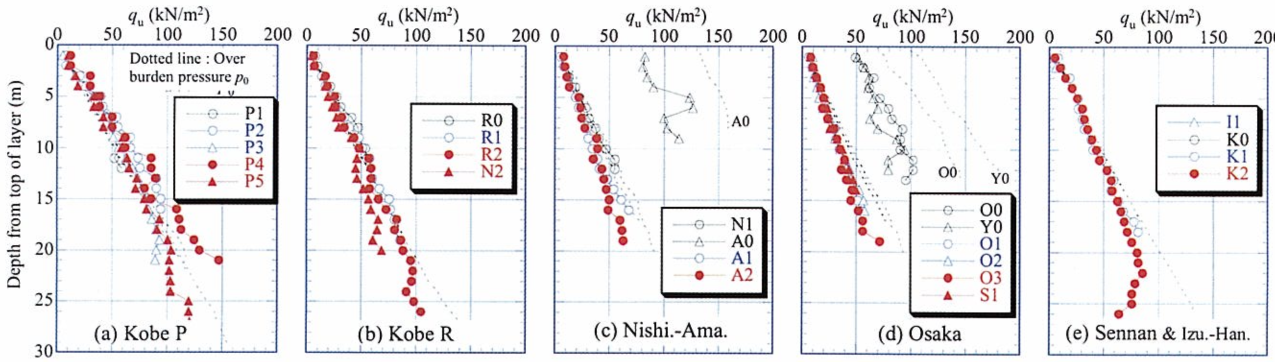


Fig.3-20 Vertical distribution of averaged unconfined compressive strength of each zone in 6 areas (Ma13)

significantly in the overconsolidated state. Those in the areas toward Osaka decrease gradually, and those in Osaka area become smallest, being located almost on the p_c-line in the normally consolidated state. Those in Sennan area become larger again in the lightly over-consolidated state.

Fig.3-20 shows the vertical distribution of averaged unconfined compressive strength q_u of each zone in 6 areas, in which the dotted lines signify the effective overburden pressure p_0. The q_u in each zone increases almost linearly with depth. The values in Kobe P area are largest among all areas, being located above the p_0-line, as in p_c. Those in the areas toward Osaka decrease gradually, and those in Osaka area become smallest, being almost half smaller than Kobe P. Those in Sennan area become larger again, showing a similar value as in Nishinomiya-Amagasaki.

Geotechnical characteristics of Pleistocene clay (Ma12) and their regional variations

(1) General remarks

The Pleistocene clays (Ma12, Ma11,etc..) deposited in Osaka Bay are lightly overconsolidated, the OCR of which is about 1.3. Because the Pleistocene clay had never subjected to a greater overburden pressure than the present one, according to the geological history, this overconsolidation was caused not by mechanical effect, but by aging effect such as due to chemical bonding between clay particles. Therefore, the Pleistocene clays in Osaka Bay is normally consolidated aged clays, which is sometimes called "quasi-overconsolidated clay (Akai et al (1981)). This consolidation characteristics is the most remarkable point for Osaka Bay Pleistocene clays, which is the main factor of large-scale long-term settlement behavior caused in the reclaimed islands in Osaka Bay (Mimura et al (2003)), as described later on.

In the following, the geotechnical characteristics and their regional differences of the Pleistocene clay are described, focusing on Ma12 clay that is deposited at the uppermost of Pleistocene layer. That is, the soil properties in each divided zone as shown in ***Fig.3-15*** are compared by the similar way as in Ma13 clay, followed by the discussion on their regional differences.

(2) Physical properties

Fig.3-21 shows the vertical distribution of averaged liquid limit of Ma12 clay in each zone. The symbols shown in the figure are the same as in Ma13 clay. That is, the symbols of the divided open, open and solid data points correspond to the coastal, near-shore and off-shore, respectively. The vertical w_L distribution of Ma12 clay in each zone is quite similar as in Ma13, classifying such three types as Kobe, Osaka and Sennan, as previously mentioned. The feature of w_L distribution in each zone is as follows:

1) Kobe P: w_L is about 80-100%, the lowest among 6 areas. All zones show Kobe type. w_L in the western part is lower, while the eastern part higher.
2) Kobe R: w_L is higher than in Kobe P. The bow-shaped distribution as in Osaka type appears. Similar in the direction of northwest to southeast, and the eastern part is higher.
3) Nishinomiya-Amagasaki: w_L distribution is bow-shaped. w_L in A1 zone is the highest, and comparatively high even in A0 zone of inland with thick layer.
4) Osaka: w_L distribution is typical bow-shaped Osaka type. In the zones of O0, O1 and O2, the uppermost layer is lost. w_L in the zones of O0 and Y0 is comparatively high with thick layer.
5) Sennan: All zones show Sennan type including I1 and H0, monotonically decreasing with depth. The difference between w_L at the top and bottom of the layer is greater.

Fig.3-22 shows the vertical distribution of liquidity index I_L of Ma12 with depth, in which the similar distribution as in Ma13 (***Fig.3-17***) can be seen. That is, the value of I_L in Kobe P is the lowest of 0.3–0.4, showing the comparative stable state of structure. The value of I_L gradually increases as approaching to Osaka, such as 0.35–0.45 in Kobe R, about 0.5 in Nishinomiya-Amagasaki, about 0.5–0.6 in Osaka excepting inland area. Then, it becomes 0.7 at the top of the layer in Sennan. In other words, the value of I_L continuously increases from Kobe to Sennan, changing the structure of clays gradually to comparatively unstable state with higher water content, in the similar way as in Ma13.

(3) Consolidation characteristics

The consolidation characteristics of Ma12 clay in each zone is described herein, focusing on the quasi-consolidation characteristics of Osaka Bay Pleistocene clay.

Fig.3-23 shows the representative compression curves (e-log$p$ curves) of each zone in 6 areas. The compression curves are located at the lower position in Kobe P area, among which the lowest in the offshore zone. Also, the shape of curves in the

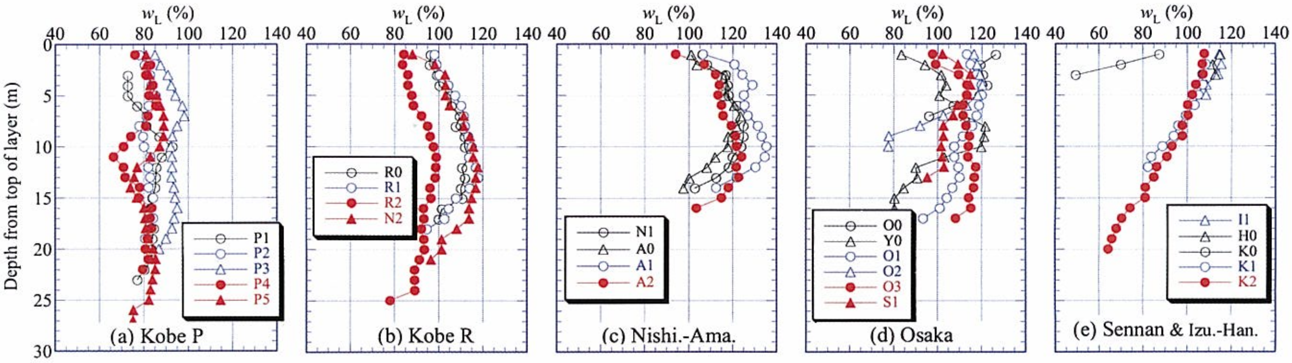


Fig.3-21 Vertical distribution of averaged liquid limit of each zone in 6 areas (Ma12)

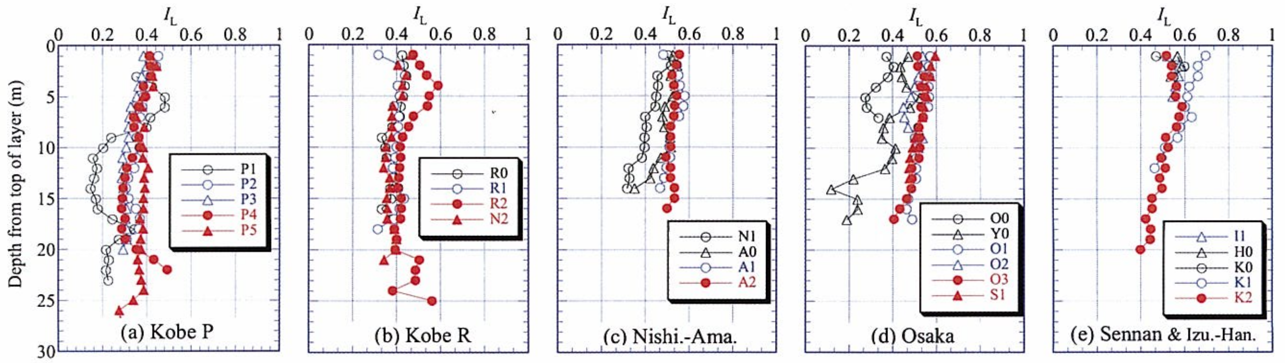


Fig.3-22 Vertical distribution of averaged liquidity index of each zone in 6 areas (Ma12)

normally consolidation part is almost linear. In the areas toward Osaka, the compression curves move upward and become concave, but no difference can be seen in between Nishinomiya-Amagasaki and Osaka or in between inland and offshore. While, the compression curves in Sennan move downward. In each figure, the standard compression curve (SCC (e_0=1.5e_L) (Tsuchida (2001)) is also shown based on the mean value of w_L. The relative positions of the compression curves to SCC tend to scatter a bit, because w_L is not the same in each zone. Approximately speaking, the compression curves in Kobe P seem to coincide with SCC, a little above SCC in the areas toward Osaka and the same trend is kept in Sennan.

Fig.3-24 shows the vertical distribution of averaged consolidation yield stress p_c of Ma12 in each zone in 6 areas, in which the dotted lines signify the effective overburden pressure p_0. These dotted lines are located in a comparatively wide range, because the elevation at the top of layer in each zone is different and the surcharge load is available in the inland area. The p_c in each zone increases almost linearly with depth, having a little bit concave trend, and p_c is generally greater than p_0, resulting in the lightly overconsolidated state. p_c in Kobe P is the greatest, then gradually decreasing toward Osaka and becomes the smallest in the areas of Osaka and Sennan, depending also on p_0.

Fig.3-25 shows the relationship between liquid limit and compression index of Ma12 in each zone, by which the regional difference in each zone can be suggested on the degree of quasi-overconsolidation of Ma12 clay. Generally speaking, the compression curve (e-log$p$ curve) of naturally deposited clay shows a little concave, and the slope of the curve becomes the maximum at just behind p_c, followed by becoming constant in the range of higher consolidation pressure. The former part of the maximum slope corresponds to the compression index C_c, while the latter part of

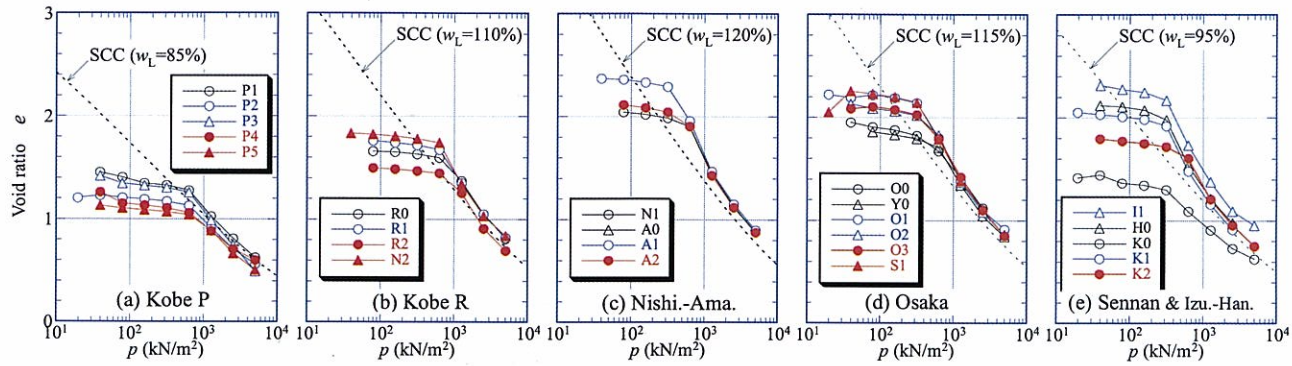


Fig.3-23 Representative compression curves of each zone in 6 areas (Ma12)

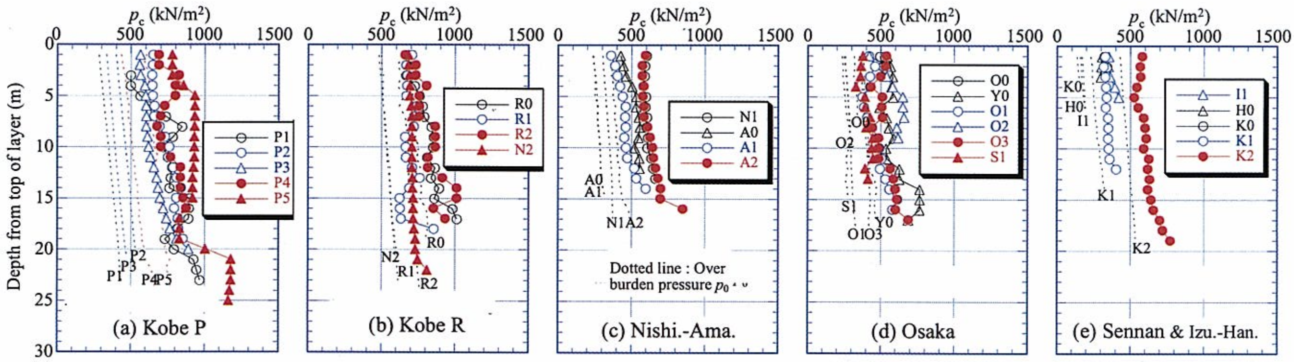


Fig.3-24 Vertical distribution of averaged consolidation yield stress of each zone in 6 areas (Ma12)

constant slope the reference compression index C_{cr} (Matsui and Sakagami (1995)), which is represented by Skempton's relationship (Skempton (1970)). It is seen from the figure that the relative position of C_c to the C_{cr} line is smaller in Kobe area, becomes higher in Nishinomiya-Amagasaki and Osaka and highest in Sennan. Therefore, the structure of clay is highly developed in Sennan, while that in Kobe area is not highly developed. The higher liquid index in Sennan previously mentioned might be caused by the highly developed structure.

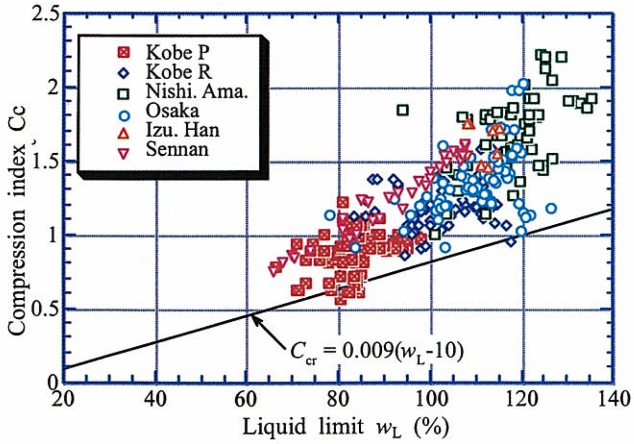


Fig.3-25 Relationship between liquid limit and compression index of Ma12 clay in 6 areas

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OYO Corp. (Kansai branch), Chuo Kaihatsu Corp. (Kansai branch), Shimizu Corp. (Kansai OHQ),
Daiho Corp. (Osaka branch), Tokyo Soil Research Co. Ltd., Fudo Construction Co. Ltd,
Kajima Corp. (Kansai branch), Hanshin Consultants Co. Ltd. (Osaka branch),
Konoike Construction Co. Ltd. (Osaka HO), Penta-Ocean Construction Co. Ltd. (Osaka branch),
Mirai Construction Co. Ltd. (Kansai branch), Taisei Corp. (Kansai branch)

KG-NET

Contact info for inquiries

Geo-Research Institute
4-3-2, Itachibori, Nishi-ku, Osaka
550-0012, JAPAN
TEL : +81-06- 6539 – 2972
FAX : +81-06- 6578 –6253
e-mail : geodick@geor.or.jp

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