J. Geotech. Eng., JSCE, No. 736/III-63, 1-17, 2003 June

GEOTECHNICAL CHARACTERISTICS AND CONSTRUCTION METHODS OF YOSHINOGARI FUN-KYU TOMB IN JAPAN AND TU-DUN TOMBS IN CHINA

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In the present study, two styles of ancient tombs, namely, Fun-kyu tomb located in Japan and Tu-Dun tomb in China were introduced first from the archaeological and cultural point of view. They are important historical patrimonies and it is archaeologically inferred that the style of Fun-kyu tomb originated from that of Tu-Dun tomb. In order to make clear the geotechnical properties and the construction methods of these man-made earthworks, geotechnical in situ investigations and laboratory tests were conducted on Yoshinogari Fun-kyu tomb in Japan and four Tu-Dun tombs in China during the two periods of 1993 and 2000~ 2001. The results of these investigations and tests will be introduced and discussed here.

Key Words: *Fun-kyu tomb, Tu-Dun tomb, field Investigation, laboratory test, archaeology, Han-chiku technique*

1. INTRODUCTION

Following the rapid advance in economy and culture, research on historical patrimony and its preservation has been attracting increasing attention of the whole society both in Japan and China during the recent years. Correspondingly, more and more geotechnical engineering researchers and technologists have been switching their research focuses to this area. By now the effective application of Geotechnics to archaeological investigations has been widely recognized[1)], and a new branch of Geotechnical Engineering, named Archaeological Geotechnics, has appeared[2)]. This has turned out to be a new and intriguing task for geotechnical research. On the other hand, the application of Geotechnics on archaeological investigation and preservation has also greatly enriched the domain of archaeological research, which has become an interdisciplinary study now.

The International Geotechnical Society set up the Technical Committee of Monuments and Historical Sites in 1981. In Japan, the Japanese Geotechnical Society also inaugurated the Technical Committee of Preservation in 1992[3)]. This Technical Committee advocates the study of 1) the relationship between archaeological remains and construction work in modern times, 2) the method of investigation for historical remains, and 3) the geotechnical techniques for preservation of historical remains. Our research group in the Civil Engineering Department of Saga University, has carried out several research projects on historical remains in Japan and China[4), 5), 6), 7)].

This paper, from the view point of Geotechnical Engineering, investigates the earth fill characteristics and construction techniques of Yoshinogari Fun-kyu tomb of Yayoi Era (B.C.300~A.D.300) in Japan and four Tu-Dun tombs in China. Tu-Dun tomb is a unique and predominant style of tombs existing exclusively within Jiangnan area during the period of Bronze Age in Chinese history, which includes the Western-Zhou Dynasty, the Spring-Autumn Period, and the Warring-States Period (about B.C.1200~B.C.222).

Historically speaking, there existed long lasting

and various cultural and technical exchanges between ancient Japan and China. It is well known that Chinese ancient culture exerted tremendous influence on many aspects of ancient Japanese society. Especially in recent years, more and more archaeological evidence show that the Jiangnan area in China, which includes Jiangsu Province, Zhejiang Province, parts of Anhui Province and Fujian Province, greatly influenced the development of ancient culture and technology of Japan. For example, it is argued by some agronomists and archaeologists that the rice culture in the late Joumon Era (B.C.8000~B.C.300) and Yayoi Era was disseminated to Japan directly from Jiangnan area over the East Sea. The style of the ancient architecture and its compact community with surrounding trenches in the Yayoi Era are associated closely with those of ancient society in the Jiangnan area[8), 9)] as well. Because of such close cultural relationship between the ancient Jiangnan area in China and Yayoi Era in Japan, it is strongly argued by some archaeologists that the construction style and techniques of the Yayoi Fun-kyu tombs correlate to those of the Tu-Dun tombs[7), 8), 10)]. Although the period that Tu-Dun tombs prevailed appeared earlier than that of Fun-kyu tombs, there was still a period about 100 years when Tu-Dun tombs and Yayoi Fun-kyu tombs coexisted. It is also reasonable to argue that the style of Tu-Dun tombs would not disappear immediately when it was no longer popular, and would be handed down for some time. Up till now, similarities between Yayoi Fun-kyu tombs in Japan and Tu-Dun tombs in China have been discussed by some archaeologists[11), 12), 13)], for example, the application of burial jars (Kame-kan, in Japanese) as coffins, the above-ground burying pattern of the dead, the outward appearance and the funerary objects, etc. Consequently, we can safely assume that the style of Fun-kyu tombs originated from that of Tu-Dun tombs to some extent.

Therefore, our research objectives are to study the following:

1. Geotechnical properties of earth fill on the Fun-kyu tomb and Tu-Dun tombs;
2. Construction techniques employed during the process of building these tombs;
3. Interrelation of construction techniques between Fun-kyu tomb and Tu-Dun tombs.

2. RESEARCH ON YOSHINOGARI FUN-KYU TOMB IN JAPAN

(1) Generation

The Yoshinogari historical remains (B.C.300~A.D.300) was discovered in Kanzaki County, Saga Prefecture in 1989 and have become a significant and famous remnant of the Yayoi Era in Japan (**Fig.1**). It includes a large body of artifacts and architectural remnants unearthed throughout the whole Yayoi Era. The Yoshinogari historical remains illustrate various aspects of people's daily life in the Yayoi Era, such as techniques of rice production, architectural style and so on[14)]. Within the Yoshinogari historical remains, one tomb was excavated whose style is given the name of Yayoi Fun-kyu in Japan (Fun-kyu means mound-shaped tomb). In this tomb large earthen jars, named Kame-kan, functioned as coffins to contain the dead. Researchers were impressed by the advanced techniques adopted in building this tomb.

(2) Field investigation

The present dimension of the Fun-kyu tomb is about 40~45m across from north to south, 26m from west to east, and 2.5m high (See **Photo 1** and **Fig.2**). In the **Fig.2**, trenches for archaeological investigation and contour lines of 20cm interval are shown as well. Based on the data of archaeological investigation, it is concluded that the tomb was build about B.C.100, and the original height of the tomb was about 4~5m.

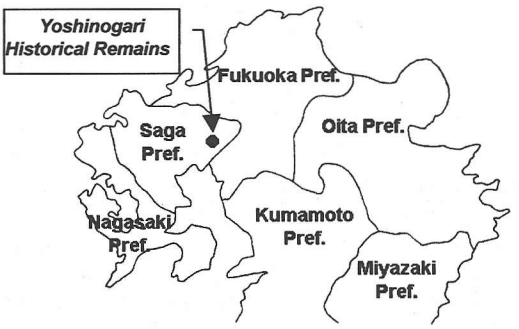


Fig.1 Location of Yoshinogari historical remains in Kyushu

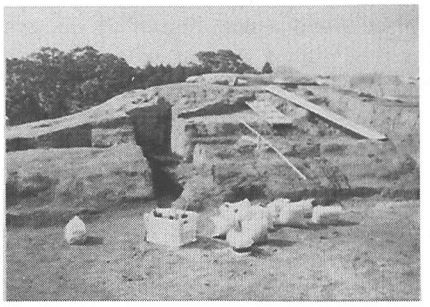


Photo 1 View of Yoshinogari Fun-kyu tomb

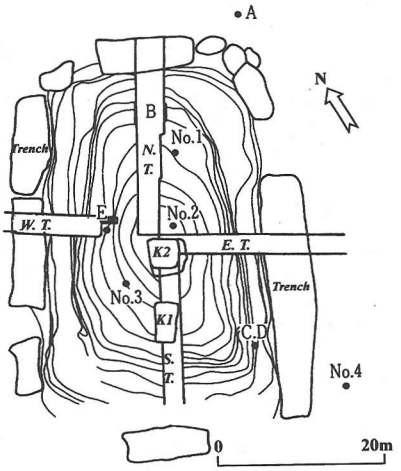


Fig. 2 Investigation plane of Yoshinogari Fun-kyu tomb
N.T.: Northern Investigation Trench; K1: Kame-kan 1;
S.T.: Southern Investigation Trench; K2: Kame-kan 2
W.T.: Western Investigation Trench;
E.T.: Eastern Investigation Trench;

SPT (Standard Penetration Test) and boring were implemented at the spots No.1, No.2, No.3 and No.4. No.1, No.2 and No.3 were within the sphere of the Fun-kyu tomb, and No.4 was outside the tomb and located at the spot of the soil remnants abandoned during the archaeological investigations carried out in 1988. The abandoned soil remnants had become rather hard, and, for the sake of comparing with the earth fill within the sphere of the tomb, sampling and boring were also conducted at No.4. In addition, at the five spots of A, C, D, E, and No.4, undisturbed block samples were obtained. C and D are the same point on the plane, but D is 30~40cm beneath C.

The cross section in the southern trench is

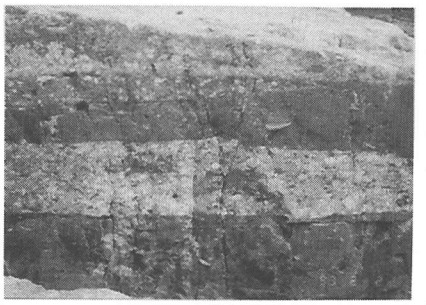


Photo 2 Layer-state earth fill of Fun-kyu tomb

shown in **Photo 2.** Layer-state rammed earth fill can be clearly seen from this photo. The term "ram" here corresponds to the conception of "compact" in the sense of Geotechnics. And this term is often adopted to archaeologically describe the action of Han-chiku, which is a kind of ancient construction technique (Explanation in details on this technique will be given in later). From this cross section, it is inferred that Han-chiku technique was utilized then to construct this tomb. Sample B is a disturbed soil sample from this compacted earth fill section.

SPT results are shown in the **Fig.3**. Within the scope of the tomb earth fill, the maximum *N* value of No.1 is 7, No.2 is 11 and No.3 is 7. The maximum *N* value at the spot of No.4 outside the tomb is 9.

We noted that *N* values at these spots are smaller on the whole than we expected. We attribute the reason to relatively high moisture content and the grain size distribution (illustrated in **Table 1**). In the **Fig.3**, we also note that *N* value below 4~5m deep from the ground surface is less than 3, and this may due to the fact that the ground beneath the tomb is mainly composed of silty clay with high moisture

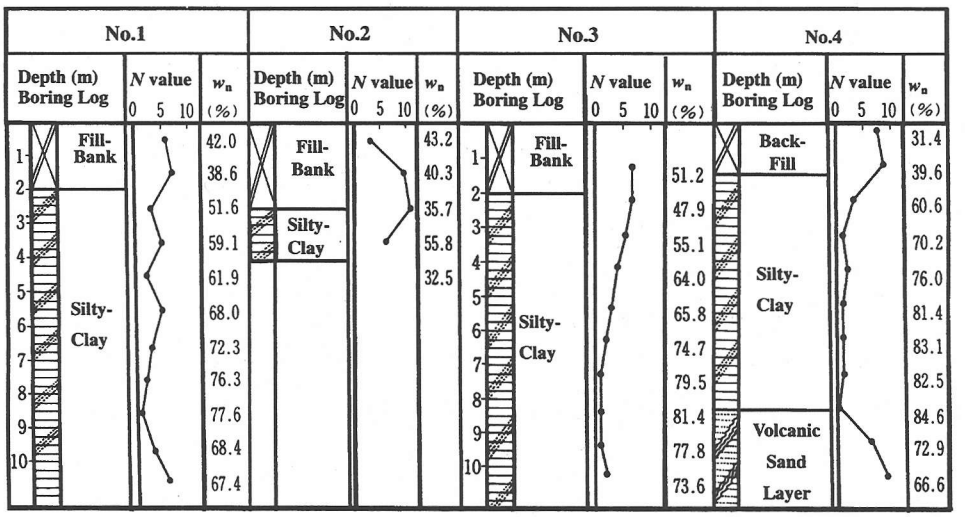


Fig.3 SPT results and boring log in Yoshinogari Fun-kyu tomb

Table 1 Physical property of samples from Fun-kyu tomb

Sample	G_s	w_n	ρ_t	w_L	w_P	I_P	Grain Size Distrubution(%)				Class.
		%	g/cm^3	%	%		gravel	sand	silt	clay	MH
A	2.681	52.0	1.53	67.6	44.1	23.5	0.6	21.1	57.8	20.5	MH
B	2.644	-	-	52.4	32.1	20.3	0.2	16.6	65.7	17.5	MH
C	2.636	48.8	1.57	63.6	39.1	24.5	0.8	18.1	44.6	36.5	MH
D	2.606	39.8	1.64	56.8	43.4	13.4	0.1	17.5	61.4	21.0	MH
E	2.605	39.7	1.75	54.0	31.6	22.4	0.1	14.2	65.2	20.5	MH
No.4	2.663	35.6	1.56	51.6	27.0	24.6	1.0	42.3	37.7	19.0	MH

Table 2 Compaction test results of Fun-kyu tomb

Sample	w_n	ρ_d	w_{opt}	ρ_{dmax}	ρ_d/ρ_{dmax}
	%	g/cm^3	%	g/cm^3	%
A	52.0	1.01	40.6	1.20	84.2
B	-	-	29.3	1.37	-
C	48.8	1.05	40.0	1.23	85.4
D	39.8	1.18	32.8	1.35	87.4
E	39.7	1.25	34.9	1.33	94.0
No.4	35.6	1.15	32.3	1.33	86.5

content. Within the scope of the tomb, underwater was not discovered; yet at No.4, underwater level was found with a depth of 9.35m.

(3) Results of laboratory test and discussion

a) Physical and chemical properties

The Yoshinogari hill land where the Fun-kyu tomb is located is mainly formed by pyroclastic sedimentary soil. The earth fill of the tomb can be assorted into loess soil, volcanic ash soil and sandy soil. The loess soil is mainly composed of fine quartz sand and illite.

The physical properties of sample A, B, C, D, E and No.4 are illustrated in **Table 1**. Among these samples, A is from original ground and shows a red color; the color of C is black brown, and the color of D and E are black. According to the X-ray analysis, the main clay mineral of sample A is hydrated halloysite. The mineral constituent of sample C is close to that of A, but a small amount of quartz was mixed in. The main mineral constituent of sample D and E are quartz similarly. The different color of these samples can be attributed to the volcanic glass particles with different color mixed into the soils.

Except sample A, all the samples are mixture of loess soil and volcanic ash soil, and came into being artificially. The amphibole contained in these samples present smashed state of fine grains, contrary to its natural state. Therefore, we can conclude that the earth fill of this tomb was dynamically compacted.

Indicated in **Table 1,** sand portion of the soil remnants at spot No.4 is 42.3%, much more than the other samples. Except samples from No.4,

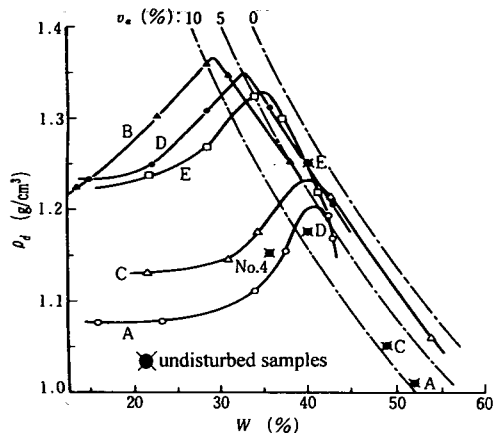


Fig. 4 Compaction curve of Fun-kyu tomb

sample A bears the most sand portion (21.1%), and the largest G_s (2.681). It can be seen that the samples D and E have almost identical properties. We therefore assume that these two samples can represent the basic properties of the earth fill of the tomb.

b) Mechanical properties of the earth fill and aging effect

Compaction test result and discussion

Listed in **Table 2** are optimum water content and maximum dry density of samples A~E and No.4. It can be seen that almost all the compaction degree, which is defined as the ratio of natural dry density to maximum dry density, are rather high up to more than 85%; and sample E, especially, achieves 94%. **Fig.4** is the compaction test curve, where the natural water content and dry density of each undisturbed sample is plotted too. It shows that the void ratios of samples A~E are less than 10%. Therefore we can conclude that the earth fill of the tomb was carefully compacted during construction and achieved considerable denser state, which can be compared favorably with that of modern construction. Overall, the earth fill around the Kame-kan coffin was denser than the other area.

Consolidation test result and discussion

The ideal *e*-log*p* curve of undisturbed natural

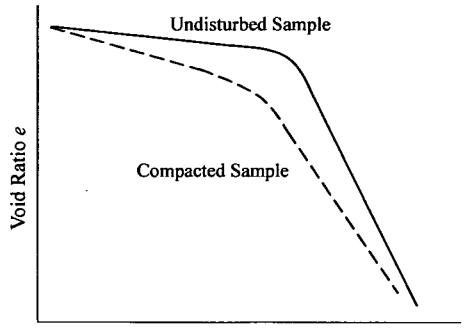


Fig. 5 Ideal *e*-log*p* curve of undisturbed sample and compacted sample with same density and water content

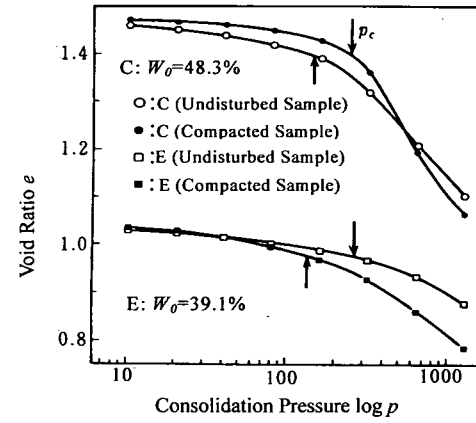


Fig. 6 *e*-log*p* curve of sample C and E

sample and compacted sample with same density and water content is shown in **Fig.5**. Due to aging effect, it is well known that p_c and C_c of undisturbed sample is bigger than that of compacted sample. From **Fig.6** it is clearly shown that although the p_c of undisturbed sample E, which came into being about 2000 years ago, are larger than that of compacted samples with same water content and dry density, the p_c of the undisturbed sample C shows less than that of the compacted sample. It is assumed that this difference in aging effect between C and E results from the different compaction degree of them. In other words, the higher the compaction degree of the earth fill, the more remarkable the aging effect on consolidation characteristics. In addition, we also regard the difference of basic soil properties of C and E as part of the reason. With regard to C_c, the aging effects on the undisturbed sample C and E are both not clear in this test.

Direct shear test result and discussion

Likewise, undisturbed samples and compacted samples with identical water content and dry density were tested under constant vertical load condition. The shear speed is 0.25mm/min, and 20, 40, 80 and 160 kN/m^2 are adopted as the vertical loads with consideration of the relatively small vertical effective stress within the tomb. From the results of sample E shown in **Fig.7**, it is indicated that there is a shear stress peak to appear during the shearing process of undisturbed sample; on the contrary, there is normally no such shear stress peak during the shearing process of compacted samples. Besides, the shear strength of undisturbed samples is conspicuously larger than that of compacted samples.

Given the condition without the occurrence of swelling, the samples underwent soaked for 24 hours in the direct shear box. The direct shear tests

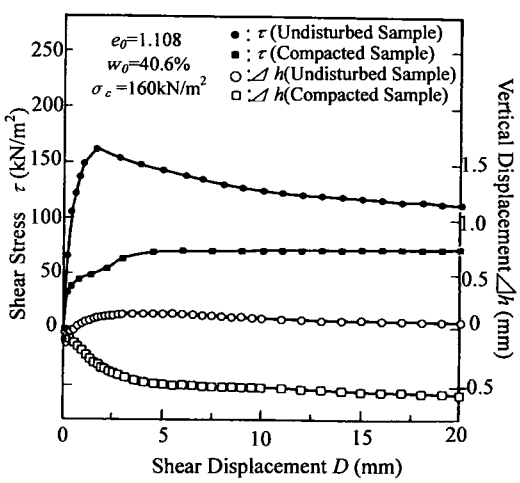


Fig.7 Direct shear stress-displacement curve of undisturbed sample and compacted sample

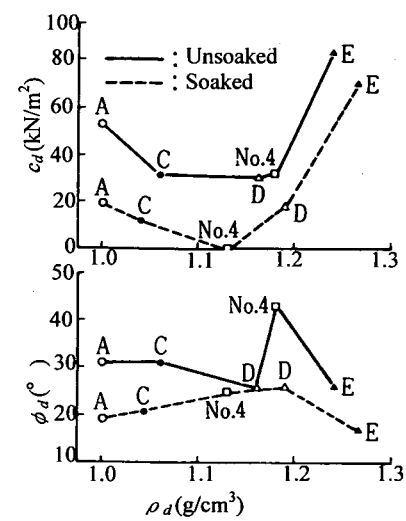


Fig.8 Direct shear strength *vs* dry density

were also conducted on these soaked undisturbed samples. The relationship of dry density *vs* shear strength parameters c_d and ϕ_d is shown respectively in **Fig.8**. Sample E showed largest cohesion among these samples, and after being soaked, cohesion decreased merely about 15% owing to aging effect. In contrast with E, the cohesion of the soaked sample at No.4 decreased to zero, although the *N* value at this spot is relatively high as 9, bigger than that of No.1 and No.3. This can be attributed to that the soil remnant at the locale of No.4 deposited only several years and cementation among soil particles was not fully developed. In addition, the sand portion of sample at No.4 is much more than other samples (**Table 1**), which brings about the maximum angle of internal friction among these samples and partly leads to the zero cohesion after being soaked.

3. RESEARCH ON TU-DUN TOMBS IN CHINA

(1) Generation

The name "Tu-Dun tomb" stemmed from its outward appearance. The two Chinese characters, "Tu" (Pronunciation of the Chinese character) that means soil, and "Dun" that means mound, are combined to describe the appearance of this kind of tomb, which is mound-shaped and constructed with soil. Mainly constructed during the period from about B.C.1200 to B.C.222, the Tu-Dun tombs are located exclusively and extensively in the Jiangnan area. As a result of the scarcity of historical remnants during the Bronze Age of Chinese history in the Jiangnan area, the research on the Tu-Dun tombs plays an important role in understanding the development of culture during this period[15]. Furthermore, the research can be conducive to exploring the origins of the distinctive Wu-Yue culture in the Jiangnan area as well.

Hilly land is typical topography in the Jiangnan area, and the Tu-Dun tombs are generally built here on small hills with an average elevation of 10~260m above sea level. These tombs have an average diameter of 6~40m, height 2~7m. The common process of construction is as follows. Firstly, clean and level the ground. Then, lay the dead directly upon the earth (During the later developing stage of the Tu-Dun tombs, wood coffins were also adopted to hold the dead.). In some cases before placing the dead, the ground surface was specially treated; such as setting up a so-called "bed" made of stones or burned soil. Finally, soil from the surroundings was backfilled

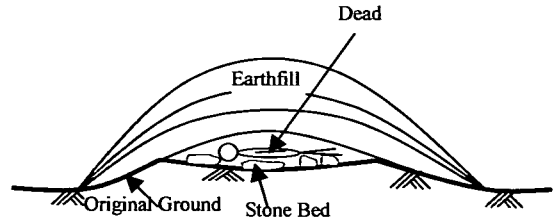


Fig. 9 Cross section of typical construction of Tu-Dun tombs

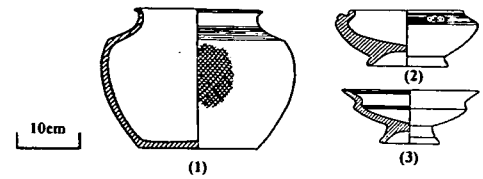


Fig. 10 Typical unearthed artifacts from Tu-Dun tombs

(1): Stamped hard pottery; (2)and(3):Primitive porcelain

to form a mound (**Fig.9**). This construction method differs from that of the tombs in northern area of China during the identical historical period. In the latter case, the dead were traditionally buried in a deeply dug pit beneath ground surface. The construction methods of the Tu-Dun tombs in the Jiangnan area were mainly due to the higher under water level and the larger precipitation in the Jiangnan area than that of northern China.

Formally speaking, two kinds of Tu-Dun tombs existed. One is described above and named as Tu-Dun tomb in this paper. The other style is Tu-Dun tombs with stone chamber that will not be discussed here.

Dead or human bones are seldom found during archaeological excavation of the Tu-Dun tombs because of decomposition of the dead. It is also not a rare case that several tombs were built into one larger mound. The typical unearthed artifacts from the Tu-Dun tombs are primitive porcelain and stamped hard pottery (**Fig. 10**).

According to Yang[16], the area where Tu-Dun tombs exist can be divided into three regions (**Fig.11**), Ⅰ :Huang Mt.-TianTai Mt. region, Ⅱ:Ningzhen region, and Ⅲ:Tai Lake-Hangzhou region. This division is based on geological differences and cultural characteristics of these areas. In the four investigated tombs, two tombs locate in Jintan (number 17 in **Figure 11**) and belong to the Ningzhen region. The other two belong to the Tai Lake-Hangzhou region and are located in Anji (number 32 in **Figure 11**).

(2) Test results and discussion of the Tu-Dun tombs in Jintan

a) Generation

The two Tu-Dun tombs investigated here are

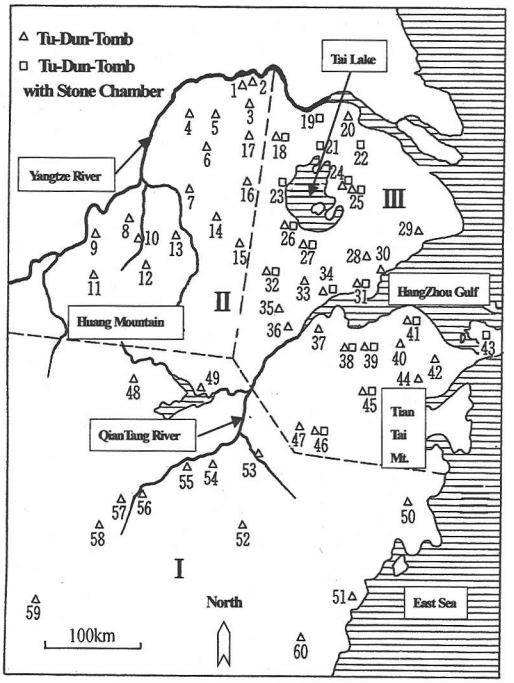


Fig. 11 Distribution of Tu-Dun tombs in Jiangnan area
I :Huang Mt.-TianTai Mt. Region;
II :Ningzhen Region; III:Tai Lake-Hangzhou Region
Some place names indicated in the figure:
1:Zhenjiang; 2:Dantu; 5:Jurong; 17:Jintan; 25:Suzhou; 27:Huzhou; 32:Anji; 34:Yuhang; 53:Jinhua; 60:Cangnan

situated on Lian hill in Xuepu town, Jintan city, Jiangsu Province, and numbered J-1 and J-2 in this paper. **Fig.12** shows the topographic plane of these two Tu-Dun tombs, and **Photo 3** is the outward appearance of J-1. The two tombs are about 60m apart with an average elevation of 50m above sea

Photo 3 General picture of Tu-Dun tomb J-1 in Jintan

level. The dimensions of the two tombs are almost identical, about 4.5m in height, 20m in diameter. From fragments of stamped hard pottery collected on the spot, it is archaeologically concluded that these two tombs were constructed during the early period of Spring-Autumn Period.

Due to the nearly identical construction method and dimensions, the following results and discussion center on Tu-Dun tomb J-1.

b) In-situ investigation results and discussion

Samples from boring reveal that the color of the earth fill varies with the depth, although the properties of the whole earth fill are nearly identical. The earth fill illustrates a dark-brown in the upper part due to the nature environmental influences, such as rain, plant matter and so forth. In the center part the earth fill illustrate a brown to pale-brown. Owing to approaching incompletely weathered base soil, the bottom part shows a red-brown.

We also conducted SPT test on the spot (The SPT test method of China is almost identical to that of Japan). As shown in the *N* value curve of SPT (**Fig.13**), the peak appeared at the spot of

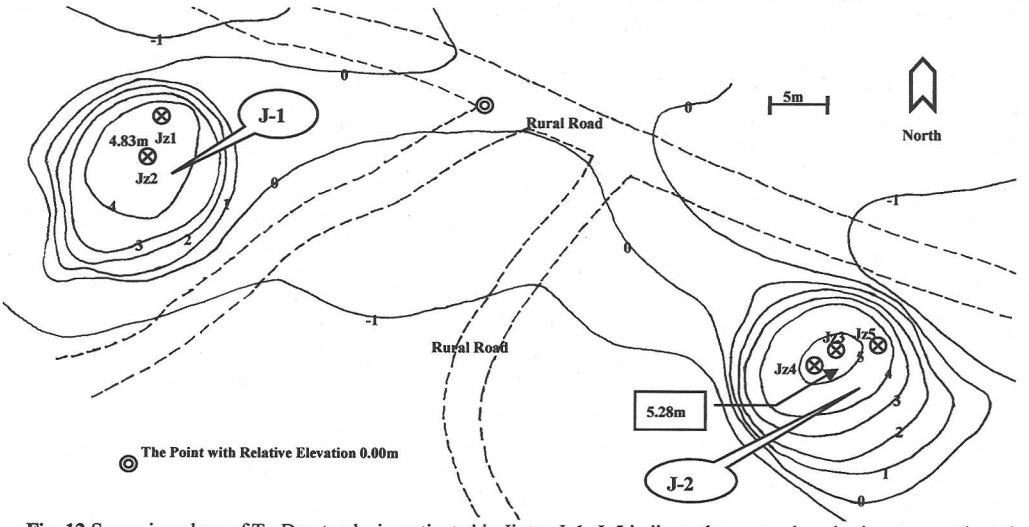


Fig. 12 Surveying plane of Tu-Dun tombs investigated in Jintan.Jz1~Jz5 indicate the spots where boring was conducted.

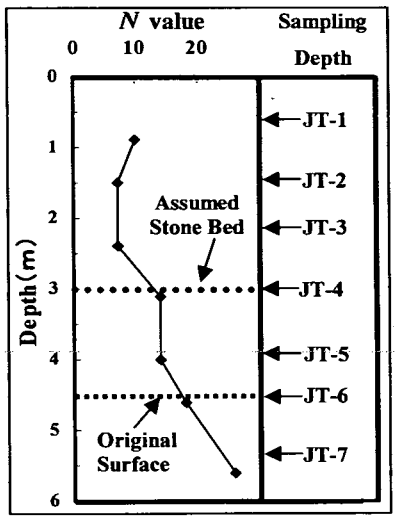


Fig.13 SPT result of Tu-Dun tomb J-1 and sampling depth

3.0m from the top of the tomb. While conducting boring, several lumps of artificial-like stone about 10cm in diameter were acquired at the depth of around 2.9m from the top. Consequently, it may be reasonably assumed that the dead had been placed on a kind of stone-bed (**Fig.9**), made up of lumps of stone about 10cm in diameter. This stone-bed resulted in the appearance of the peak in the SPT curve.

c) Laboratory test and discussion

Physical test

Table 3 is a summary of basic properties of the earth fill samples numbered from JT-1 to JT-7 sampled by boring (**Fig.13**). From the data, it is clearly shown that for all the tested samples the percentage of silt plus clay exceeds 95%; hence the earth fill of the tomb is categorized as CL according to JGS0051. Also note that the percentage of sand and gravel of the sample JT-4, which is sampled from the section of the assumed stone-bed, shows a little larger than any other samples. This may, more or less, be the result of the stone-bed.

Compaction test

The sample of compaction test was a mixture of earth fill from upper 3m part of the tomb. In the process of the test, three different levels of compaction energy were adopted, which were standard effort (550kN-m/m^3, 25 blows/layer), reduced effort (330kN-m/m^3, 15 blows/layer), and modified effort (1100kN-m/m^3, 50 blows/layer). From **Fig.14**, we can see that the maximum dry density and optimum water content in cases of standard effort and modified effort are about same,

Table 3 Physical properties of samples from Tu-Dun tomb J-1

Sample	Depth	G_s	w_n	ρ_t	ρ_d	I_P	Grain Size Distrubution(%)				Class.
	m		%	g/cm^3	g/cm^3		gravel	sand	silt	clay	
JT-1	0.6/0.8	2.71	22.9	1.84	1.50	20.2	1.1	1.6	45.4	51.9	CL
JT-2	1.3/1.5	2.71	25.1	1.97	1.57	20.9	1.2	2.6	44.8	51.4	CL
JT-3	2.0/2.2	2.71	24.7	1.83	1.47	20.8	1.3	2.8	49.8	46.1	CL
JT-4	2.8/3.0	2.70	24.7	1.90	1.52	16.4	1.6	3.0	54.3	41.1	CL
JT-5	3.8/4.0	2.72	26.0	1.99	1.58	20.6	1.2	1.8	49.6	47.4	CL
JT-6	4.4/4.6	2.71	21.6	1.98	1.63	17.6	0.2	1.1	52.7	46.0	CL
JT-7	5.3/5.5	2.70	21.5	2.03	1.67	16.7	1.0	1.9	57.0	40.1	CL

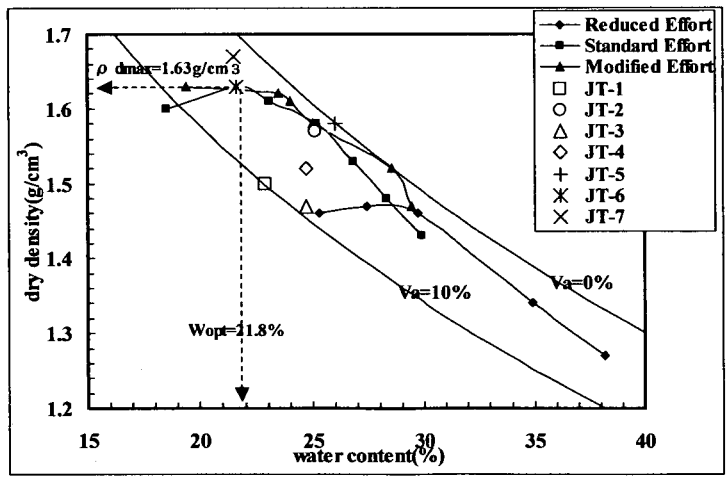
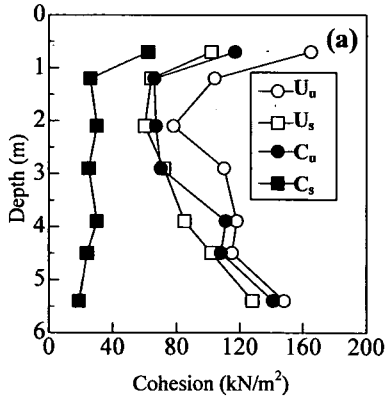


Fig. 14 Result curve of compaction test on Tu-Dun tomb J-1 in Jintan



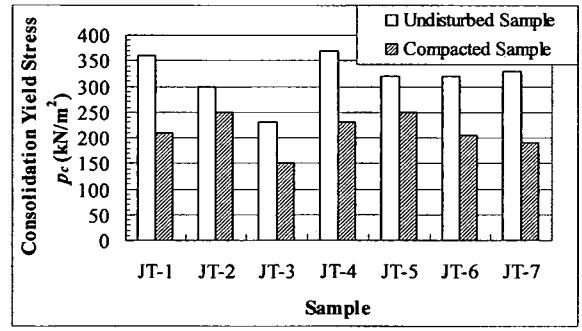


Fig.16 Comparison of p_c results of undisturbed and compacted samples

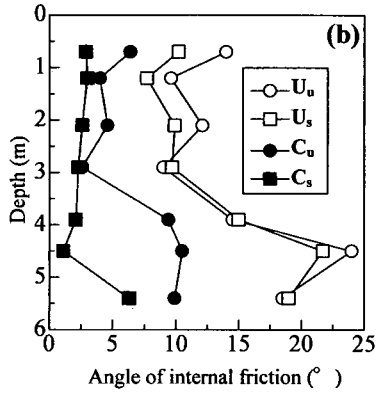


Fig.15 Direct shear test results of Tu-Dun tomb J-1

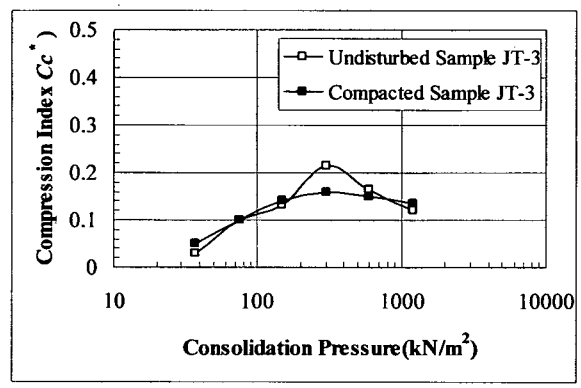


Fig.17 C_c^* *vs* consolidation pressure

maximum dry density 1.63g/cm^3, and optimum water content 21.8%. In addition, the dry density and water content of undisturbed samples JT-1 to JT-7 are also marked in this figure. It is clearly indicated that all the samples have volume ratio of air void less than 10%. The compaction degrees of the undisturbed samples are also calculated: JT-1 is 93%, JT-2 is 96.3%, JT-3 is 90.2% and JT-4 is 93.3. Thus it is obvious that the earth fill of the tomb achieved rather dense state.

Direct shear test

Four kinds of samples were tested: undisturbed unsoaked sample (abbreviated as U_u), undisturbed soaked sample (U_s), compacted unsoaked sample (C_u) and compacted soaked sample (C_s). Herein compacted sample are those samples made by compaction with water content and dry density identical to undisturbed samples. Sample soaking method is identical to the aforementioned direct shear tests in the case of Yoshinogari Fun-kyu tomb. The shear speed is 0.8mm/min, and 20, 40, 80 and 160 kN/m^2 are also adopted as the vertical loads. The choice of vertical loads results from the consideration of the relatively small vertical effective stress within the tomb, and meanwhile the purpose of comparing the test results between the Yoshinogari Fun-kyu tomb and Tu-Dun tombs.

The relationship of the depth from the top of Tu-Dun tomb J-1 *vs.* shear strength parameters c and ϕ are shown respectively in **Fig.15(a)** and **(b)**. The cohesion of U_u samples varies from about 80kN/m^{2}kPa to 180kN/m^2 showing much greater than that of C_u samples as a whole. From **Fig.15(a)** we can also note that the cohesion variance between U_u and U_s is smaller than that between C_u and C_s. These results can be explained as about 2000 years aging effect on cohesion. This result demonstrates similarity of aging effect on cohesion of the earth fill with that of Yoshinogari Fun-kyu tomb.

As to the angle of internal friction ϕ, it is shown in **Fig.15(b)** that ϕ of U_u samples is larger than that of C_u samples. Similar to the previous analysis of cohesion, the variance of ϕ between U_u and U_s is smaller than that between C_u and C_s. It appears that for the earth fill of Tu-Dun tomb J-1, aging effect exerted similar influence on change of the cohesion and angle of internal friction.

Consolidation test

Besides undisturbed samples, compacted samples with water content and dry density identical to the undisturbed sample were also

tested to investigate the aging effect on consolidation characteristics of the earth fill.

The p_c results are plotted in **Fig.16**. It is clearly shown that the undisturbed samples bear bigger p_c than compacted samples, which is similar to that of Yoshinogari Fun-kyu tomb.

The relationship between consolidation pressure *vs* compression index C_c^* of the undisturbed and compacted sample JT-3 is drawn in **Fig.17**. Normally, the compression index, C_c, is equal to the slope of the field consolidation curve plotted to a logarithmic scale of consolidation pressure p in the linear range. Herein, C_c^* is still expressed by the equation $\Delta e / \Delta \log p$, but calculated at every consolidation pressure in the e-log$p$ curve. We can note that near p_c of the undisturbed sample JT-3 C_c^* has a distinct peak, whereas C_c^* of the compacted sample has no such obvious peak. The other sections of the two curves, however, are close to each other. Mesri[17] has argued that for natural clay the difference between undisturbed sample and remolded sample on consolidation characteristics is that whether a peak appears in the relationship of consolidation pressure *vs* compression index C_c^* due to aging effect. Hence, from the test results illustrated above it can be concluded that aging effect on consolidation characteristics of this man-made earth fill is similar to that of natural clay. This can be attributed to that the earth fill has undergone about 2500 years and behaviors as naturally deposited clay.

(3) Test Results and Discussion of the Tu-Dun Tombs in Anji

a) Generation

The two Tu-Dun tombs investigated here are located in Long Hill, Gucheng village, Anji county of Zhejiang Province. They were archaeologically judged to be built during the later Spring-Autumn Period and are consecutively numbered D141 and D142 by the Management Bureau of Historic Relics of Zhejiang Province.

The surveying plane was drawn in **Fig.18**. The larger one, numbered D141, has a height of about 8.0m and an elevation of about 40m above sea level. It has an elliptical plane, from north to south about 50m along the major axis, from west to east about 40m along the minor axis. The small one has a round plane with a diameter of about 20m, height of about 3m. The following content will be concentrated on the tomb D141.

Before our investigation, the eastern part of the earth fill on the tomb D141 had already been partially cut out by brick works in order to acquire the soil materials for the manufacture of brick. We made use of this partially cut out section to excavate a trench vertically from the top of the tomb to the bottom so that we can get the full view of the earth fill structure (**Photo 4**). This trench is 2m wide and 1m deep horizontally. Meanwhile, during the process of excavating the trench, undisturbed samples AJ1~AJ7 were also obtained at the vertical depths of 1.00m, 1.80m, 2.75m, 4.00m, 5.35m, 6.50m, and 7.40m from the top (**Fig.21**). Moreover, undisturbed samples were also obtained by boring at the spot Az2 (**Fig.18**).

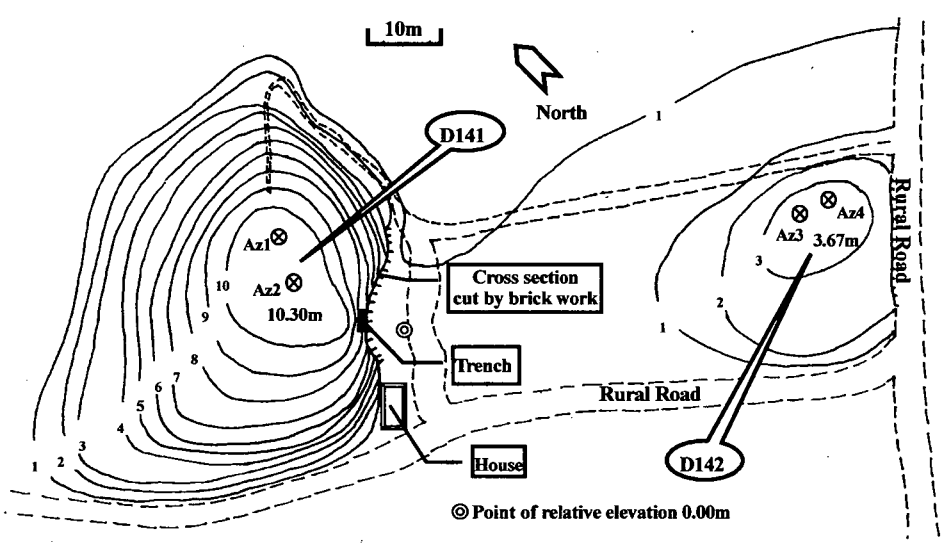


Fig.18 Surveying plane of Tu-Dun tomb D141 and D142 investigated in AnJi
Az1~Az4 indicate the spots where boring was conducted.

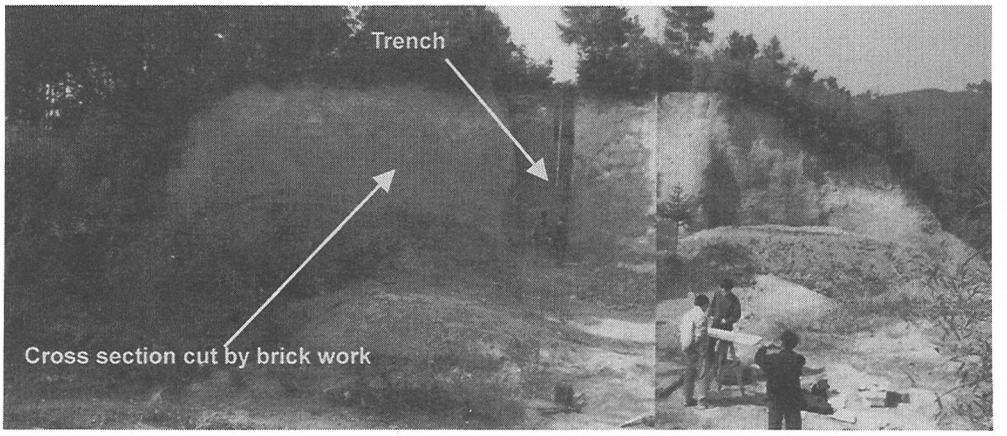


Photo 4 Outward appearance of Tu-Dun tomb D141 in Anji
A 2m wide and 1m deep trench was excavated in the central part of vertical cross section.

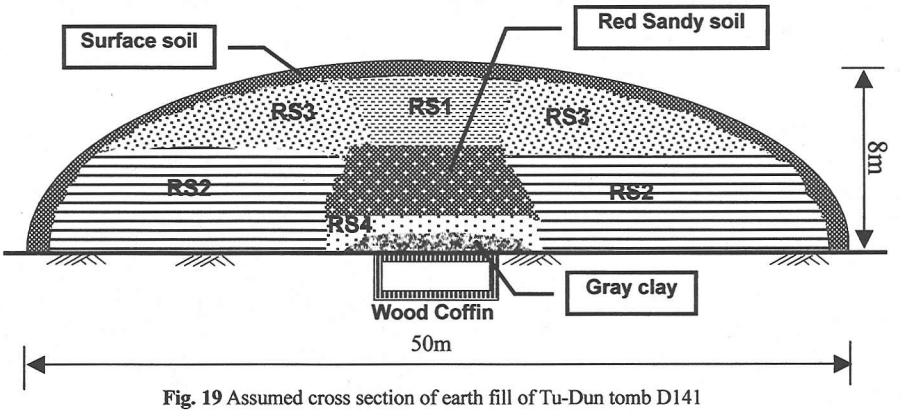


Fig. 19 Assumed cross section of earth fill of Tu-Dun tomb D141

b) In-situ investigation results and discussion

According to in-situ observation and results from various tests, the assumed cross section of the earth fill of the tomb D141 is shown in **Fig.19**. As indicated, the earth fill of this tomb can be divided into four sections, which are surface soil, rammed soil, red sandy soil and grey clay.

Surface soil

About 1m thick surface soil displays color from dark brown to light brown downwards because of external influence of natural factors upon it, such as rain, wind, human activities, plants, etc. Also, particles of charcoal were found to scatter within this layer. Shown in **Table 4**, the portion of clay and silt particle approximates to 85%. Therefore the soil in this layer is classified as CL.

Rammed soil

By analyzing the cross section and test results of the earth fill, it is revealed that the traditional Han-chiku technique was applied in constructing the earth fill of the tomb. Here we will give some details on the Han-chiku technique.

Dated from about B.C.2000, the Han-chiku technique was widely used as a practical and effective construction method in construction projects that ranged from dwellings, to city walls, foundations, and dams and tombs in ancient China, as well as in ancient Japan.

Literally, the two characters "Han" and "Chiku" of the term Han-chiku in ancient Chinese represented the two elementary tools employed in the Han-chiku technique: tamper (Han) and shuttering boards (Chiku). Simply, the Han-chiku technique is a kind of ramming method, or compaction method in the geotechnical sense. The common process of this method is described as follows (**Fig.20**). At first, shuttering boards are set up along the contour of the construction project in accordance with the design scheme. Then, a layer of soil material is paved within the space formed by the shuttering boards. The soil materials could be a kind of unmixed soil, or a mixture of soil and other building materials such as sand, etc. After one layer is deposited, tamping (compaction) will be implemented, which would follow specific construction norms, such as times and location of

Table 4 Physical properties of undisturbed samples from Tu-Dun tomb D141

Sample	Depth	G_s	w_n	ρ_t	ρ_d	I_P	Grain Size Distrubution(%)				Class.
	m		%	g/cm^3	g/cm^3		gravel	sand	silt	clay	
AJ-1	1.00	2.69	16.8	1.64	1.40	13.8	2.7	12.0	51.2	34.1	CL
AJ-2	1.80	2.69	17.0	1.73	1.48	12.9	2.2	10.4	49.6	37.8	CL
AJ-3	2.75	2.70	19.6	1.76	1.47	12.8	5.7	14.9	57.9	21.5	CL
AJ-4	4.00	2.70	15.9	1.96	1.74	13.9	9.6	29.7	29.8	30.9	CL
AJ-5	5.35	2.66	14.4	1.93	1.64	6.9	2.5	47.7	30.1	19.7	SF
AJ-6	6.50	2.66	23.3	1.85	1.50	11.5	0.5	14.8	50.3	34.4	CL
AJ-7	7.40	2.69	20.8	2.06	1.70	9.1	0.0	3.5	49.6	46.9	CL

Table 5 Geotechnical properties of samples obtained from some historical remains

Sample	G_s	I_P	w_n	Grain Size Distrubution(%)				Class.	Yamanaka Type
			%	gravel	sand	silt	clay		Hardness Gauge(mm)
A	2.67	15.5	2.1	0.0	1.0	80.7	18.3	CL	36～37
B	2.66	17.1	1.9	0.0	1.8	91.0	7.2	CL	35～37
C	2.71	14.9	19.1	15.5	23.0	22.7	38.8	CL	35～37

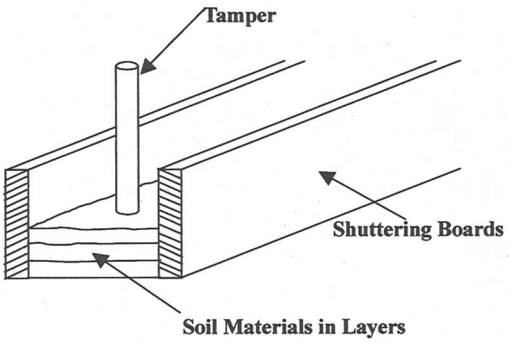


Fig. 20 Sketch of Han-chiku technique

Photo 5 8m high basement of A-Pang Palace constructed by means of Han-Chiku technique

tamping on one layer of soil materials. This process of setting up shuttering boards, paving soil materials, and tamping, is repeated until the project is completed.

In China and Japan there are a myriad of historic remains constructed by the Han-chiku technique. For instance, the ancient sections of the Great Wall built before Ming Dynasty was constructed by employing the Han-chiku technique. Even nowadays this technique is still used in some areas of China, for soil is available almost anywhere and the construction method is relatively simple.

One example of Han-chiku historic remains is illustrated in **Photo 5**. This is a basement of a giant palace located in the outskirts of Xi'An city, named A-Pang Palace, which was constructed under the command of the Shi-Emperor of the Qin Dynasty (B.C.221~B.C.207). This basement had an original area of 500m×1300m. The present dimension is 200m × 100m, 10m high. This basement was wholly constructed with yellow loess by employing the Han-chiku technique, wherein the compacted layer is about 8~10cm. The geotechnical properties of soil samples A and B from this basement is shown in **Table 5**. The hardness of the surface compacted soil approaches that of stone.

In **Photo 6** is shown a 1.8m long ramming hamper, used in building the YinShan tomb of Yun-Chang, who was the King of Yue-State (located in Zhejiang Province) in the later Spring-Autumn Period (about B.C.450). This tomb is a large-scale Tu-Dun tomb and was wholly constructed by Han-chiku technique. One Han-chiku layer of the earth fill is 7~9cm thick. The geotechnical properties of earth fill sample C from this tomb is also shown in **Table 5**. During our investigations on Yoshinogari Fun-kyu tomb and Tu-Dun tombs, however, ramming hampers were not found.

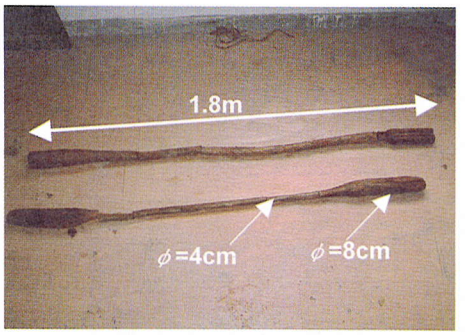


Photo 6 Two ramming hampers used in Han-chiku

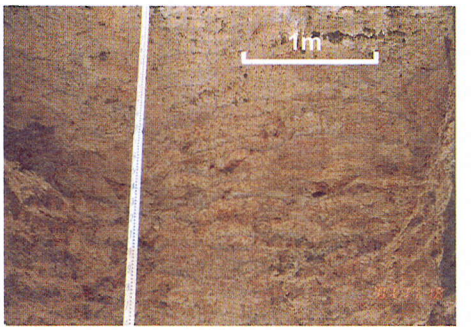


Photo 7 Rammed soil layers in RS1Part

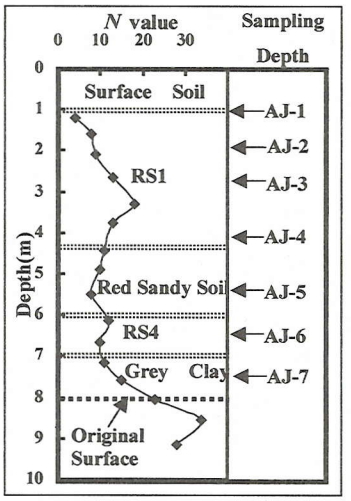


Fig.21 SPT results of Tu-Dun tomb D141 and sampling depth

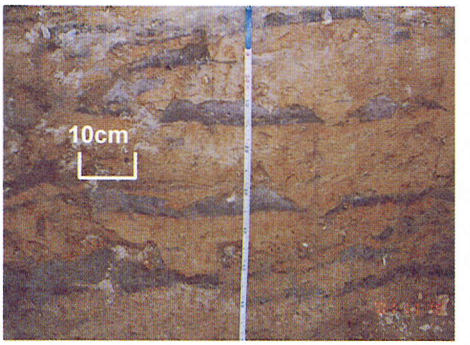


Photo 8 Rammed soil layers in RS2 part

The rammed earth fill of Tu-Dun tomb D141 can be assorted into four parts, RS1, RS2, RS3 and RS4 (herein RS means Rammed Soil, see **Fig.19**).

In RS1 (**Photo 7**), carefully compacted layer-state earth fill is clearly shown with each layer about 10-15cm thick. Meanwhile, fine gravel and sand are also found mixed into this compacted soil. These are key features of employing Han-chiku technique herein. From grain size distribution of sample AJ-4 (**Table 4**) sampled in this section, it is illustrated clearly that the grain size distribution in this sample is conspicuously distinct from other samples, that is, the proportion of sand, silt and clay are almost identical and the proportion of gravel is outstandingly greater than others samples. Consequently, well-graded state of grain size was achieved and earth fill under this state can be compacted far more densely. Moreover, referring to **Fig.21**, the peak of *N* Value also appeared in this part. All of this indicates that this section was carefully compacted and attained a rather dense state. With regards to function, this section of soil strengthened the entire structure of the tomb, as well as serving as a successful waterproof measure to some extent due to its dense state.

From **Photo 8**, we can see that RS2 is another typical Han-chiku earth fill. Between the 10~15cm thick layers of cohesive soil, 3~5cm thick red sandy soil layers were sandwiched. Owing to the excellent permeability of water, sandy soil layers absorbed surplus moisture contained in adjacent cohesive soil layers when these layers were compacted. Thus, along with this drainage of moisture that originally existed in the void spaces between soil particles, soil particles became closer and a much denser state could be reached. Moreover, since sandy soil layers bear higher strength themselves than cohesive soil layers, the total strength of this section was enhanced. The aforesaid is also the reason why in the Han-chiku technique one layer of sand, gravel, broken stone, or broken brick is frequently sandwiched between two cohesive soil layers. Because these layers of red sandy soil also formed a continuous plane extending to the edge of this tomb, it is assumed that the layers of red sandy soil may also function as drainage to drain off the water that seeped inwards to the edge of the tomb.

RS3 is considered to be a mixture of surplus soil left over during construction of the tomb, consisting of cohesive soil, red sandy soil and grey

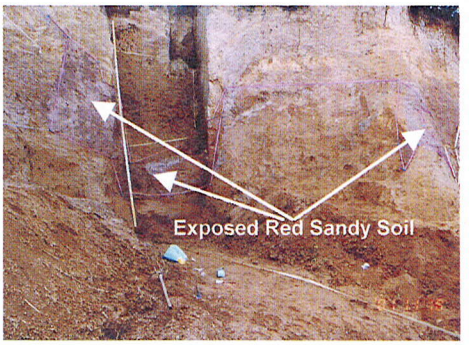


Photo 9 Red sandy soil part in Tu-Dun tomb D141

Photo 10 Grey clay part in Tu-Dun tomb D141

clay. RS4 is made up of cohesive soil, acting as an interim layer between sections of red sandy soil and grey soil in the central section of the tomb.

Red sandy soil

During the in situ investigation, the red sandy soil section and grey soil section in the central part of the tomb are especially spectacular, not only for their colors, but also for their functions. The section of red sandy soil (**Photo 9**) has a trapezoid cross section and composes purplish red sand, classified as SF (namely, fine sand) according to the soil classification criterion based on grain size distribution (**Table 4**).

As for the function of this section, two aspects should be considered. The first aspect is based on the demand of engineering. Since sandy soil bears high permeability of water, by the means of setting up this layer the water permeating from upper layers can be diverted to the periphery of the tomb. Hence a water-drainage effect can be achieved. Additionally, since sandy soil has high strength itself, setting up this section also improved the stability and durability of the whole tomb.

The second consideration originated from a cultural factor. About 5,300 to 4,000 years ago, scattered widely around the lower reaches of the Yangtze River in the Tai Lake basin of the Jiangnan area was a branch of highly developed Neolithic culture where advanced paddy farming tools, black pottery of unique forms and delicately carved jades were buried. Since a large amount of historical remains and cultural relics belonging to this culture were discovered in the Liangzhu town of Yuhang city, located in the southern tip of the Grand Canal of Zhejiang Province, this Neolithic culture was named Liangzhu culture. Liangzhu culture is regarded as the first light of dawn in Chinese civilization and exerted a tremendous influence on the development of ancient culture of the Jiangnan area[18), 19)]. Within the scope of the Liangzhu remains, several sacrificial altars were excavated. Without exception, the earth fills of the altars were constituted by three-color soils, yellow, red and grey. Therefore it is argued by archaeologists specializing in Liangzhu culture that these three-color soils had turned out to become regular symbols in sacrificial sites and had some special sacrificial connotation. In the earth fill of Tu-Dun tomb D141, three-color soils, yellow-rammed soil, red sandy soil and grey clay, also appeared. Consequently, we assume that this set-up of three-color soils in the Tu-Dun tombs must relate to Liangzhu culture and resulted from religious belief. However, it is still not clear from where this red sandy soil was obtained.

Grey clay

The grey clay (**Photo 10**) was often functioned as hermetical and waterproof material to cover the central part of ancient tombs in China. For example, in the tomb of Yun-Chang mentioned above, a large quantity of this grey clay was used as hermetical and waterproof material to protect the coffin of the King Yun-Chang. The clay is known as Qing-Gao mud (blue cream mud in English) in Chinese and generally can be gathered from the rice paddy fields. From the **Table 4**, we can see that the proportion of silt and clay of sample AJ-7 sampled in this section accounts for 96.5%. In addition, as listed in **Table 6**, the dry density of undisturbed sample in this part is 1.70g/cm^3. Whereas the available maximum dry density in laboratory compaction test is 1.71g/cm^3, thus the degree of compaction reaches 99.4%. All of the above results tell us that this section had achieved an extremely dense state that leads to considerably low permeability of water in this section so that the inner tomb can be preserved in dry condition as far as possible.

c) Laboratory test and discussion

The physical test results are listed in **Table 4**. Except that AJ-5 from the red sandy soil is classified as SF (fine sand), all the other samples

Table 6 Results of compaction test of Tu-Dun tomb D141

Soil Sample	ρ_{dmax}	w_{opt}	ρ_d	w	Compaction Degree
	g/cm^3	%	g/cm^3	%	%
above 4m	1.76	17.7	1.59	17	90.2
Red Sandy Soil	1.95	12.7	1.75	14	89.7
Grey Clay	1.71	19.3	1.70	21	99.4

Table 7 Results of direct shear test and consolidation test

Depth	c	ϕ	Cc	p_c
m	kN/m^2	°		kN/m^2
1.40/1.60	72	9.6	0.11	250
2.05/2.25	-	-	-	
2.65/2.85	54	23.7	0.28	250
3.20/3.40	67	21.4	0.29	340
3.85/4.05	73	20.5	0.15	260
4.50/4.75	45	28.8	0.17	210
5.20/5.40	70	6.7	0.14	210
8.35/8.55	113	19.8	0.10	300

are classified as clay. In the compaction test, three earth fill samples were tested, which are mixtures of earth fill samples from the upper 4m part of the trench, red sandy soil and grey clay respectively. From **Table 6**, we can see that the compaction degree of all these samples exceed 90%, particularly 99.4% in the case of grey clay. This rather dense state can match that of construction projects employing modern machines. The results of consolidation test and direct shear test are illustrated in **Table 7**. The samples of the consolidation test and direct shear test were sampled by boring at the spot Az1 (**Fig. 18**).

4. CONCLUSION

In order to draw a conclusion, a brief comparison was conducted as shown in **Table 8**. In accordance with the three research objectives given in the INTRODUCTION, we will summarize this paper into the following two parts:

(1) Geotechnical properties of earth fill

In respect of engineering properties, we see that the earth fills of these three tombs overall have a rather dense state. For Yoshinogari Fun-kyu tomb the compaction degree of the earth fill is more than 85%, and the void ratios of all samples collected within scope of the tomb are less than 10%. For Tu-Dun tomb J-1, all the undisturbed samples have volume of air void less than 10% and average compaction degree is about 93%. For Tu-Dun tomb D141, compaction degree as a whole exceeds 90%.

In this paper we also discussed the aging effect on man-made earth fills of these tombs. In consolidation test results, we noted that the p_c of undisturbed sample which came into being about 2000 years ago, are bigger than that of compacted samples. Moreover, it also appears that the higher the compaction degree of the earth fills, the more remarkable the aging effect on p_c. In the discussion of Tu-Dun tomb J-1, aging effect on compression index is also analyzed.

The aging effect on cohesion of soil is clearly shown through direct shear test results. It is also indicated by the results of Tu-Dun tomb J-1 that aging effect gives rise to the change of internal friction angle similar to that of cohesion.

(2) Construction method of earth fills

In this paper, a kind of ancient construction method, Han-chiku technique, was introduced. Based on the in situ investigation and analysis carried out in this paper, we know that this is the very technique used both in Yoshinogari Fun-kyu-Tomb and Tu-Dun tomb D141. In Yoshinogari Fun-kyu tomb, this method was

Table 8 Comparison between Tu-Dun tombs in China and Fun-kyu tomb in Japan

Tomb	Tu-Dun Tomb J-1	Tu-Dun Tomb D141	Fun-kyu Tomb
Construction time	about B.C.700	about B.C.400	about B.C.100~B.C.50
Dimension(length/width/height:m)	20/20/4.5	50/40/8	45/26/4
Status of the dead	populace	aristocrat	governer
Variety of the earthfill	single	divesity	divesity
Classification of the main earthfill	CL	CL	MH
Maximum of N Value	14	18	11
Degree of compaction(%)	93.0	89.7~99.4	84.2~94.0
Construction method	-	Han-chiku	Han-chiku
Thickness of comapcted layer	-	10~15cm	10~30cm

adopted to build the principle section around Kame-kan. In the earth fill of Tu-Dun tomb D141, two typical Han-chiku soil materials were found out. One is the mixture of soil and sand, and the other is the combination of soil layer and sand layer. Based on this similarity of construction method of Tu-Dun tombs and Fun-kyu tombs, along with other commonalties, it can be reasonably inferred that cultural characteristics and construction methods of the Tu-Dun tombs in China must have influenced those of the Yoshinogari Fun-kyu tomb in Japan to some extent.

Generally speaking, the construction methods of Tu-Dun tombs varied in accordance with the status of the dead. For tombs of the populace, people merely gathered earth fill of a single kind from the surroundings, and then banked it up to form a mound. However, in order to construct grand-scale Tu-Dun tombs for the aristocracy, several different kinds of soil were used to achieve certain engineering and religious functions. When considering enduring durability, the Han-chiku technique was often adopted in constructing a tomb.

Furthermore, through this research, the construction level of earthwork during the period of Tu-Dun tombs in the Jiangnan area has also been brought to light. People then had known that by making use of specific kinds of soil, some engineering requirements could be fulfilled. For example, using sand as drainage materials, and using clay as waterproof materials. Meanwhile, the development of the Han-chiku technique in the Jiangnan area is also revealed. The degree of compaction is as high as 90%~99% demonstrating the advanced level of construction techniques.

To continue this research, investigation is underway on another type of Tu-Dun tomb, a Tu-Dun tomb with a stone chamber. By comparing the construction techniques employed in the Tu-Dun tombs with the stone chamber in China and Ko-fun tombs in Japan, it will help us to further reveal the relationship between the construction of tombs in ancient China and Japan. Moreover, we hope that our efforts will pave the way for a greater understanding with regards to how the science of civil engineering was communicated between China and Japan.

ACKNOWLEDGEMENTS: This research is supported by Japan Scientific Research Assistant Fund B2: "Transition of Construction Method from Tu-Dun Tomb in Jiangnan Area, China to Yoshinogari Fun-kyu Tomb, Japan", and herein we express hearty thanks to the financial grant. We also express our wholehearted gratitude to Professor Mingda Wang and Professor Min Zhang, who are our cooperators in this research in China.

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(Received May 15, 2002)

日本・吉野ヶ里墳丘墓と中国・江南土とん墓の地盤工学特性と構築技術

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日本は古くから中国との交流があり，特に江南地方との関係が深いと言われている．日本佐賀県の吉野ヶ里墳丘墓の源流は中国の江南地方に点在する土とん遺跡ではないかと考えられる．著者らは吉野ヶ里墳丘墓と中国・江南における四つの土とん墓に対して地盤工学的現場調査と室内試験を実施し，吉野ヶ里墳丘墓と江南土とん墓の盛土の地盤工学特性を明らかにした.両遺跡の盛土はよく締め固められており，当時の先端の土木技術が駆使されているようである．両遺跡の構築には，版築工法を使ったことが確認され，共通の版築工法は両遺跡の密接な関連性を表している．