

# SEISMIC HAZARD IN TAKAMATSU JAPAN

Shuichi HASEGAWA, Minoru YAMANAKA, Hitoshi OHTA

Kagawa University

Akihiko SAITO

Shikoku Research Institute

**ABSTRACT:** The harbor city Takamatsu has population 420,000 and situated on the northern shore of Shikoku Island, southwest Japan. Downtown of Takamatsu is located mainly on delta and fill-up lands and was extensively damaged by storm surge due to No.0416 typhoon in 2004. Earthquakes in the Nankai Trough, typically of magnitude more than M 8, have been extensive damaging to the city every hundreds years and the next one is expected to occur before middle of 21st century. Deltic deposit of downtown of Takamatsu is composed of the Holocene sandy sediments. The reclaimed lands are composed of unconsolidated sandy and silty sediments, dredged soils and waste materials. Therefore, liquefaction and successive tsunami of 2m+ are the serious threat to the city. This paper estimates the seismic hazards in Takamatsu from the study of past disasters and liquefaction risk by the help of geo-informatics.

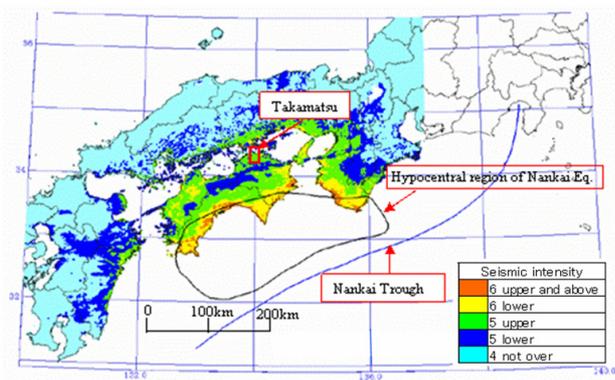
**KEYWORDS:** seismic hazard, liquefaction, Nankai Earthquake

## 1. INTRODUCTION

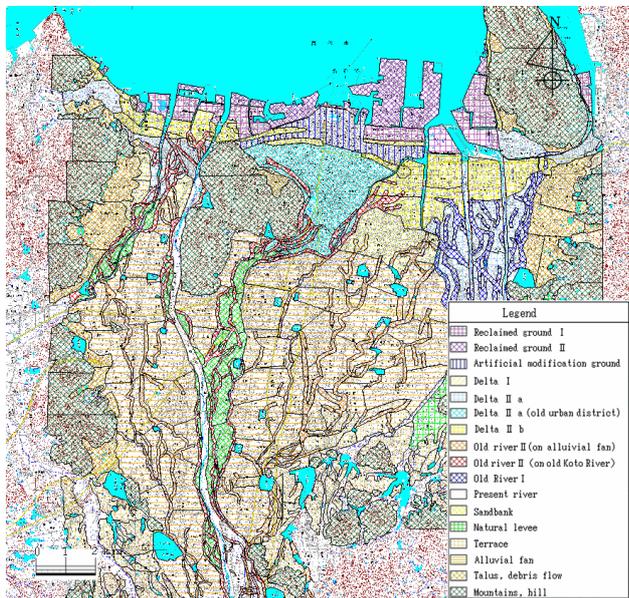
Takamatsu is situated on the northern shore of Shikoku Island, southwest Japan. Shikoku Island is situated on the Eurasian Plate. About 120-180km from south coast of Shikoku, the Philippine Plate is subducting beneath the Eurasian Plate along the Nankai Trough. Earthquakes in the Nankai Trough, typically of magnitude M 8+, have been considered the primary source of seismic hazard for the island and Takamatsu. Takamatsu has suffered serious damage by the Nankai Earthquake in past. The Headquarters for Earthquake Research Promotion (2005) estimated that the probability of the next Nankai Earthquake is 50% within 30 years from 2005, and it is 80% within 50 years. Estimation of seismic intensity of future Nankai Earthquake is shown in Figure 1.

Downtown of Takamatsu is located mainly on delta and reclaimed lands, and urban areas are developing on the fan of Koto River and the flood plain of other rivers (Figure 2). As the ground level of delta and reclaimed lands is usually below 3m, tsunami caused by Nankai Earthquake and flood storm surge by typhoon are great threat to Takamatsu city. In addition, earthquake shaking can be easily simplified in delta and reclaimed lands, thus the city has great risk of liquefaction. Therefore combined research on earthquake tremor, liquefaction and tsunami is necessary to estimate the seismic hazards associated with future Nankai Earthquake.

This paper comprehensively deals with the seismic hazards in Takamatsu by the help of past disasters and liquefaction risk on the basis of geo-informatics and geographic information system.



**Figure 1.** Estimation of seismic intensity for future Nankai Earthquake (modified from Central Disaster Prevention Council, 2003)

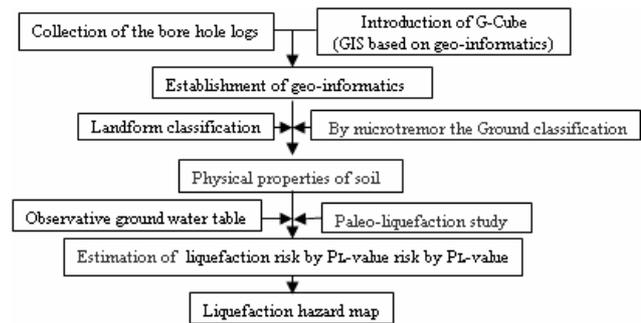


**Figure 2.** Micro-topography of Takamatsu Plain

## 2. METHODOLOGY

The objective of this study is to estimate the seismic hazards in Takamatsu from study of past disasters and liquefaction risk by the help of geo-informatics. First we have developed geo-informatics by using G-Cube (Integration Ground Information Management System by Chuo Kaihatsu Co., Ltd.) and about 1,500 borehole logs are registered into the geo-informatics. The ground conditions are classified into three categories by the help of micro-topography and microtremor

observation. The liquefaction risk is also estimated on the basis of  $P_L$ -value (Figure 3).



**Figure 3.** Flow chart of the research

## 3. TOPOGRAPHY AND SURFACE GEOLOGY

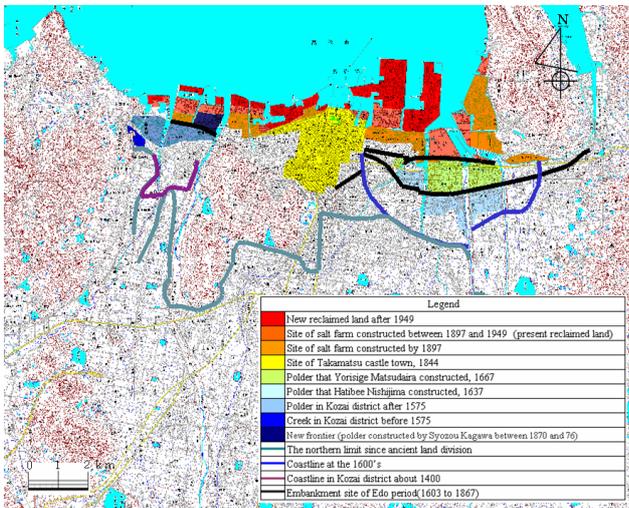
The Takamatsu plain is mainly composed of the alluvial fan of the Koto River, the subordinate flood plains of the Shin, Kasuga and Honzu Rivers, deltas of these rivers, and landfills along shore (Figures 2). Downtown Takamatsu is mainly located on deltaic deposits and the urban area is developing on the fan of Koto River, flood plains of other rivers and reclaimed lands.

This Koto River fan has been formed since the glacial age and consists of gravels and sand. The surface of the fan is covered by thin sandy and silty layers of Holocene age. Several paleo-channels have been recognized by micro-topographical and archaeological study.

The flood plains of minor rivers consist of soft sandy and muddy deposits. The deltas of these rivers are mainly composed of soft sandy and silty deposits of Holocene age. The delta deposits have thickness less than 10m (Kawamura, 2000) and cover the Pleistocene fan deposits of the Koto River.

Reclaimed lands have been developed for paddy fields and salt pans since the 17th century and salt pans were filled up in 1970s (Figure 4). These area are composed of soft sandy deposits, dredged soils and waste materials.

The surrounding hills are composed of late Cretaceous granitic rocks and middle Miocene volcanic rocks.



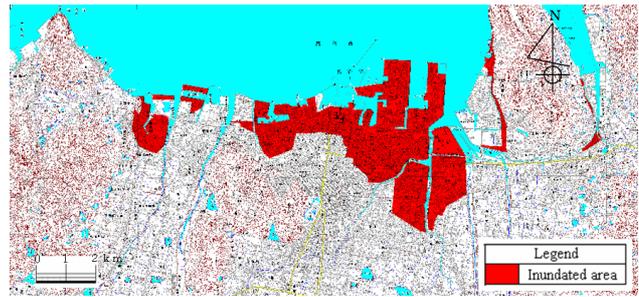
**Figure 4.** History of land use on Takamatsu Plain

## 4. PAST DISASTERS

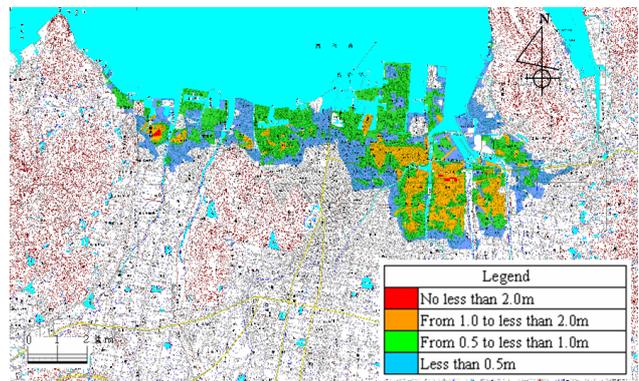
### 4.1 Typhoon in 2004

Takamatsu city was severely damaged by Typhoon Nos.0416 and 0423 in 2004.

Typhoon No.0416 caused storm surge disaster on Aug. 30<sup>th</sup> to 31<sup>th</sup>. Storm surge at Takamatsu harbour recorded 2.46m above sea level, which have exceeded past record to 0.64m. As the height of most revetment around Takamatsu port have been designed to be only 2.05m, sea water flew into the downtown area and about 15,600 houses were inundated. The inundated area by Typhoon No.0416 (Figure 5) is almost same inundated area by Nankai Earthquake tsunami estimated from Kagawa Prefecture (Figure 6). This indicates that the Nankai Earthquake tsunami will cause severe damage in downtown Takamatsu.

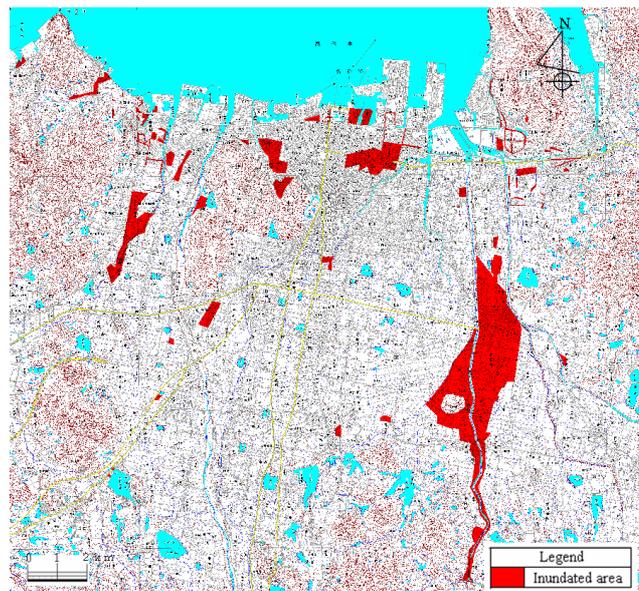


**Figure 5.** Inundated area by storm surge due to Typhoon No.0416 in Takamatsu (modified from Takamatsu city, 2004)



**Figure 6.** Flood area by Nankai Earthquake tsunami estimated from Kagawa Prefecture (2004)

Typhoon No.0423 caused flood along the Kasuga and Honzu rivers on Oct. 20<sup>th</sup> and about 5,600 houses were inundated (Figure 7).



**Figure 7.** Inundated area by Typhoon No.0423 in Takamatsu (modified from Takamatsu city, 2004)

## 4.2 Past Nankai Earthquake

The earthquakes along the Nankai Trough (Nankai Earthquakes) have been documented since 684AD (Usami,T.1987). The mean recurrence time of the Nankai Earthquakes is about 200 years before 1605AD and about 100 years after 1605. However, recent paleo-seismological studies using paleo-liquefaction data have revealed that there is a possibility of undocumented Nankai Earthquakes before 1605. Historical destructive earthquake in Takamatsu area are given in Table 1.

Historical records illustrates that almost every Nankai Earthquake caused severe damage at downtown area of delta and fan deposits. On the contrary, Showa-Nankai Earthquakes caused liquefaction only in reclaimed land, salt field and landfills.

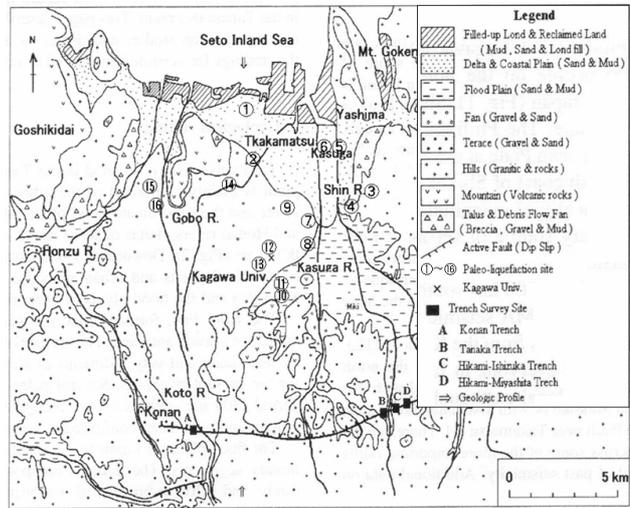
**Table 1.** Historical destructive earthquakes in Takamatsu

Date	Name of earthquake	Magnitude	JMA seismic intensity	Disasters
1596.9.6	Keicho-Kinki	7.5±1/4	5	Collapse of shrines and temples
1707.10.28	Hoei	8.4	6	Collapse of Mt.Gokenzan, Liquefaction, Tsunami 1.3m
1854.12.24	Ansei-Nankai	8.4	6	Liquefaction, Tsunami 0.3m
1946.12.21	Showa-Nankai	8	5	Liquefaction, Settlement, Tsunami 1.0m

## 4.3 Paleo-liquefaction sites

The 16 paleo-liquefaction sites in Takamatsu plain have been reported by archaeologist (Kinoshita, 2000, and Oshima, 1996). According to these reports, the 9 sites of the paleo-liquefaction are located on the Koto Fan and 7 sites are located on the delta (Figure 8). It is interesting to note that the paleo-liquefaction sites are concentrated on the eastern part of the Koto Fan. Detailed survey of micro-topography and archaeology have demonstrated that most of the paleo-liquefaction

sites are located along the paleo-channels in reclaimed land or marshes on the fan(Hasegawa& Finn,2002).

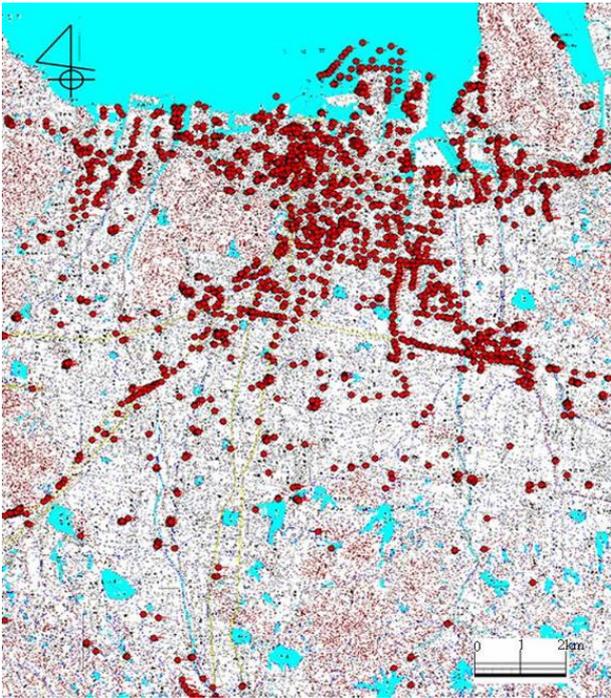


**Figure 8.** Outline of topography of Takamatsu area including liquefaction sites

## 5. DEVELOPMENT OF GEO-INFORMATICS

The geo-informatics developed in GIS consists of information of geography, geology, subsoil, N-value, and ground water (Nishie et al, 2000).

Figure 9 shows the locality of borehole logs used to prepare database of Takamatsu area. Many borehole logs data are distributed around urban area and national highways include seashore. By the cooperation of public institutions such as Ministry of Land, Infrastructure and Transport and Takamatsu City Office, registered was possible to collect boring data have reached about 1,500.



**Figure 9.** Locality of borehole logs in Takamatsu plain

## 6. MICROTREMOR OBSERVATION

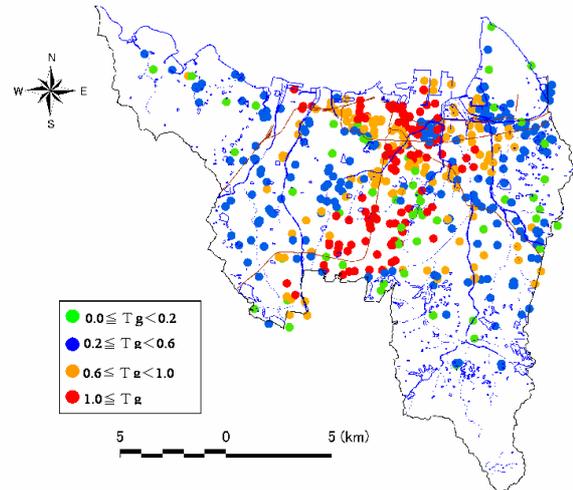
The microtremor has been observed at about 400 points in Takamatsu plain (Figures 10 and 11). The predominant period of the ground ( $T_g$ ) is estimated by the period of the maximum ratio of the H/V spectrum. The ground is divided into three types by the predominant period (Table 2).

The Class-I grounds in Takamatsu plain are mountainous area, hill and a part of alluvial fan. The Class-II grounds are old reclaimed land, old delta belt, alluvial fan, natural levee and talus. The Class-III grounds are new reclaimed land, modified land, new delta belt and a part of the alluvial fan.

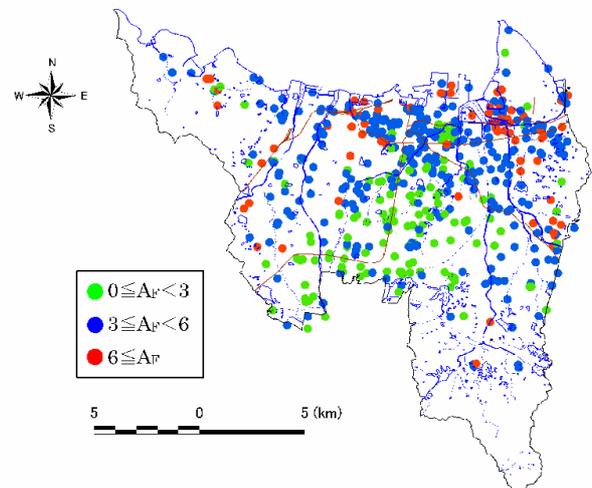
Figure 10 suggests an interesting fact that long predominant period of the Koto River fan is originated from thick Quaternary sediments. Thickness of the Quaternary sediments coincides with borehole data.

**Table 2.** Classification of ground type by the predominant period (Japan Road Association)

Classification	Predominant period ( $T_g$ )	Relative Hardness
Class-I	$T_g < 0.2$	Hardness
Class-II	$0.2 \leq T_g < 0.6$	Medium
Class-III	$0.6 \leq T_g$	Softness



**Figure 10.** Distribution of predominant period in Takamatsu Plain



**Figure 11.** Distribution of amplification factor in Takamatsu Plain

## 7. LIQUEFACTION RISK OF TAKAMATSU

The liquefaction risk was judged by potential  $P_L$ -value which is obtained by integrating liquefaction resistance  $F_L$  for the ground depth (Japan Road Association, 2002). The liquefaction resistance  $F_L$  is calculated obtained by N-value of the standard penetration test. The standard soil properties are used for calculation of  $P_L$ -value.

Table 3 shows the criteria of liquefaction risk using  $P_L$ -value by the method of Public Works Research Institute, Ministry of Construction (1981). If  $P_L$  is larger than 15, this ground is judged as the risk are of very high liquefaction.

Table 4 shows standard horizontal seismic coefficient for main two types of earthquake. Type-I earthquakes are giant subduction earthquakes such as the 1923 Kanto Earthquake and 1946 Nankai Earthquake. Type-II earthquakes are inland shallow earthquakes such as the 1995 Hyogoken-Nanbu Earthquake. We have used the horizontal seismic coefficient of Type-I earthquake. The regional correction coefficient ( $C_Z$ ) of the study area is 0.85.

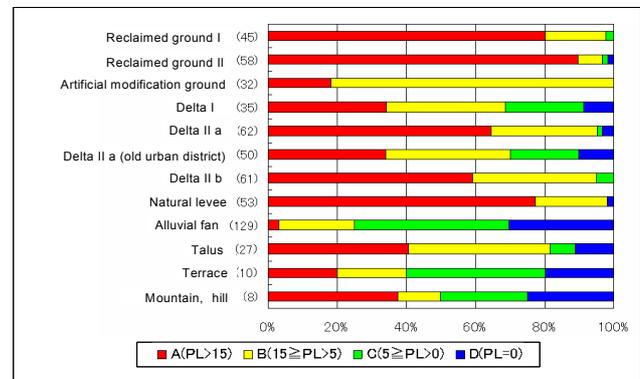
**Table 3.** Criteria of liquefaction risk using  $P_L$  value (Public works research institute of Construction, 1981)

$P_L$ value	Rank	Judgment of liquefaction occurrence
$15 < P_L$	A	A risk of the liquefaction is very high.
$5 < P_L \leq 15$	B	A risk of the liquefaction is high.
$0 < P_L \leq 5$	C	A risk of the liquefaction is low.
$P_L = 0$	D	A risk of the liquefaction is very low.

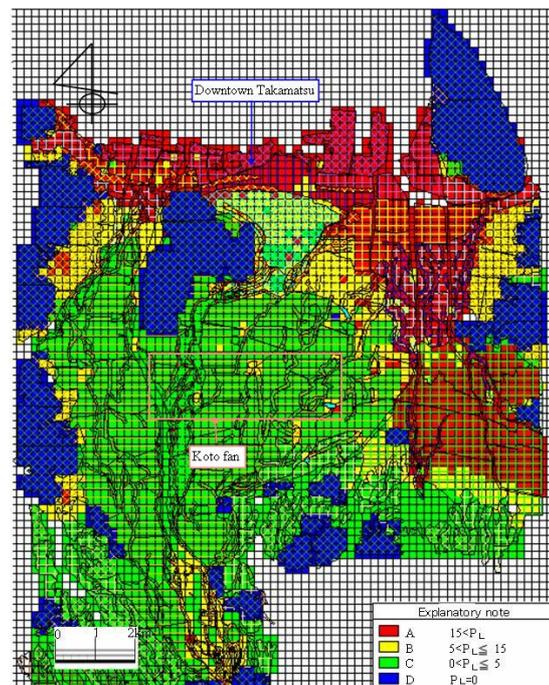
**Table 4.** Standard horizontal seismic coefficient (Japan Road Association, 1996)

Ground Type Classification	Earthquake	
	Type-I	Type-II
Class-I	0.30	0.80
Class-II	0.35	0.70
Class-III	0.40	0.60

The liquefaction hazard map of Takamatsu city for the Type-I earthquake is shown in Figure 13. The study area is divided into grids of 200m in width. In the case of several borehole logs or result of different liquefaction risk estimation in grid, the highest  $P_L$ -value is adopted (Figure 12). The grids which do not have borehole log are considered as area of highest rate of liquefaction risk in each micro-topography. This map suggests that risk of liquefaction is very high at area like reclaimed land, delta in north of Takamatsu plain and flood plain along the Shin and Kasuga rivers.



**Figure 12.** Liquefaction risk of micro-topographic zone



**Figure 13.** Liquefaction hazard map of Takamatsu city for the Type-I earthquake

## 8. SEISMIC HAZARD OF TAKAMATSU

Earthquakes in the Nankai Trough, typically of magnitude within more than M 8, have caused extensive damage in the city every hundred years and next big earthquake is expected to occur before the middle of 21st century.

Downtown Takamatsu is composed of Holocene sandy deltaic sediments. Reclaimed lands are composed of soft sandy and silty deposits, dredged soils and waste materials which have very high risk of liquefaction (Figure 13) and amplification of tremors (Figures 10 and 11). Unfortunately almost all seawall and bank have designed neither as earthquake proof nor to deduce liquefaction. Therefore, liquefaction and successive tsunami (2m+) (Figure 6) are a serious threat to the city near shore.

Reclaimed lands have been used for paddy fields and salt pans since the 17th century and salt pans were infilled in 1970's. The damage of houses and peoples were relatively few during the last three Nankai Earthquakes, because only few people lived on reclaimed lands and salt pans during the past Nankai Earthquakes. But the situation has been completely changed since the latest Nankai Earthquake of 1946. Today reclaimed lands are developed as industrial zone and dense residential area.

The tsunami flood hazard map (Figure 6) and high tide flood area (Figure 5) clearly shows that the reclaimed lands for paddy fields are lower than new landfill area near the shore. This topography will cause deeper and longer inundation in the past reclaimed paddy field area and will cause destructive damage by next Nankai Earthquake tsunami.

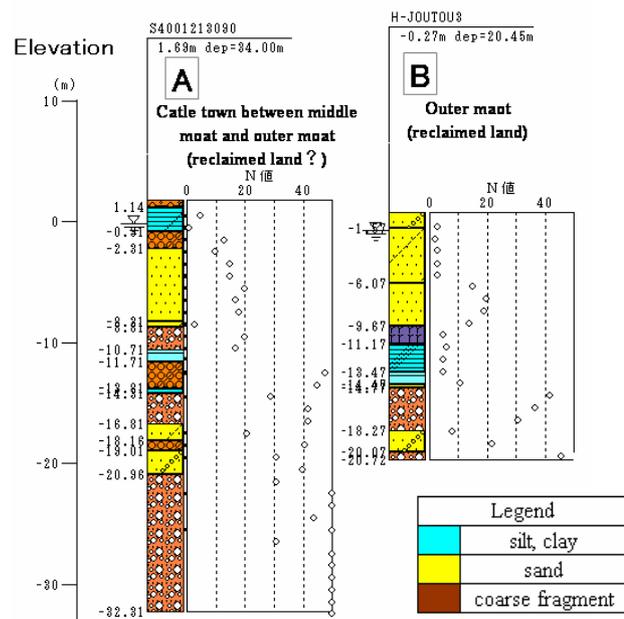
The liquefaction hazard map (Figure 13) and inundation map by typhoon No.0423 (Figure 7) also suggest that inundated areas and their vicinities are highly liquefiable and have possibility of inundation

due to collapse of river banks caused by liquefaction of grounds. Unfortunately, these areas have been developed for new residential area.

Local ground conditions are very important for estimating seismic hazards. At the center of downtown, old moats of Takamatsu castle had been filled-up and have been used for commercial area. Figure 14 shows the locality of filled-up moats from Kagawa History Museum. The borehole logs indicate that filled-up moats are very weak and can be liquefy easily (Figure 15).



**Figure 14.** Locality of filled-up moats in the center of downtown area (Kagawa History Museum)



**Figure 15.** Borehole logs of filled-up moats in the center of downtown area

## 9. CONCLUSIONS

Following conclusions are made from this study:

- 1) Downtown Takamatsu is located on Holocene delta and reclaimed lands have very high risk of liquefaction and amplification of tremors.
- 2) Liquefaction and successive tsunami (2m+) are a serious threat to the city near shore.
- 3) The lower ground level of the ancient reclaimed paddy field area will face destructive damage by next Nankai Earthquake tsunami.
- 4) The flood-prone areas and their vicinities are highly liquefiable and the damage of river banks due to liquefaction might occur.
- 5) Local intensive damage will occur in the filled-up moats in downtown Takamatsu.

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