THE SUB-BOTTOM ARCHAEOLOGICAL SITES OF LAKE BIWA (JAPAN) -LESSONS FOR THE MODERN WATER-FRONT REGION ON EARTHQUAKE DISASTER-

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ABSTRACT

Archaeological village ruins discovered in the bottom of Lake Biwa should be the records of tectonic and non-tectonic movement of coastal ground and its influence on the history and development of coastal towns from the medieval ages. Recent investigations in the Naoe-senken (village) of the eastern coast of Lake Biwa revealed that liquefaction of coastal ground (soft sand) induced landslides moved into Lake Biwa. Modern cities are intensively developed until coastal line on the similar ground condition around large lakes and ponds. The archaeological and geological investigations on sub-bottom village ruins in Lake Biwa should point out the hazard risk and provide the assessment for sustainability of the modern water front cities.

1. INTRODUCTION

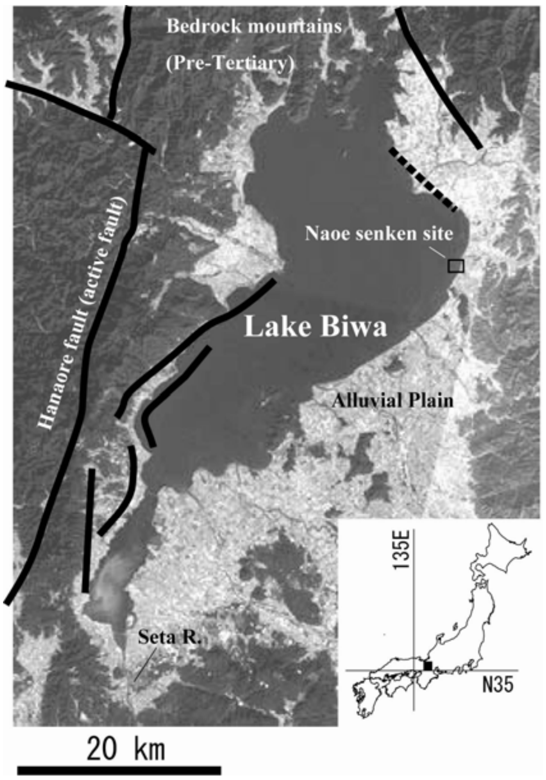

Figure 1. Index map of the Naoe-senken in Lake Biwa.

Lake Biwa is in central Japan covering 670 square kilometers, is the largest freshwater lake in Japan. The lake is also said to be one of the ancient lake in the world, dating back some 5 to 6 million years (Huzita *et.al*, 1973). There are more than 450 rivers and streams flowing into the lake, whereas there is only one natural outlet, the Seta River, so that the lake-level has been controlled by a weir at the outlet.

The area around Lake Biwa was once called Omi. Adjacent to the country's political center, Kyoto, Omi district used to be transportation hub between east and west Japan in traditionally. There are abundant archaeological evidences to indicate the coastal region of Lake Biwa; the Omi district was developed since the ancient times in Japan. Because the archaeological achievements, mostly stonewares and ceramics were also derived from the bottom of Lake Biwa, the existence of sub bottom archaeological sites in Lake Biwa was already known in 18th century. The modern archaeological survey with dry-up method on a few sub-bottom sites was intensively conducted from 1977 to 1991, however, the cause of the sub-bottom sites has been discussed, and geological, geotechnical approaches were needed to understand it. We conducted interdisciplinary studies using by methods of archaeology, geology, and geo-technology to make clear the cause of the sub-bottom archaeological sites, especially submerged village ruins called the Naoe-senken in Lake Biwa.

During Japan’s pursuit of rapid economic growth in the postwar period, urbanization in this district changed the coastal environment and system of land use. The archaeological and geological investigations on sub-bottom village ruins in Lake Biwa should provide the assessment for sustainability of the modern water front cities.

2. SUB-BOTTOM ARCHAEOLOGICAL SITES IN LAKE BIWA

Eighty (80) to one hundred (100) sub-bottom archaeological sites are known in Lake Biwa. The age of sites are widely distributed from the Jomon era (the Neolithic age in Japan) to the 19th century. Sub-bottom archaeological sites in Japan were also discovered from Suwa Lake (central Japan) and Abashiri Lake (Hokkaido, Japan); however, Lake Biwa is a world-wide rare case that a lot of submerged ruins concentrate on the same region in the lake.

Although typical submerged ruins in other case were found in shipwrecks, more than twelve (12) submerged ruins of villages (sunken vilaages) or habitation sites were found in the northern part of Lake Biwa (Fig. 2). To discuss the origin of these types of sub-bottom sites, the rising of lake-level or ground subsidence needs to explain the origin of the submerged ruins in Lake Biwa. The exact records on the lake-level changes in Lake Biwa were known from 1718. The lake level during 18th century was higher about 1 m than the controlled normal lake level in modern age (+84.371 m). Although there were no exact measurements on the lake level before 1718, some historical evidences on the elevation of archaeological sites indicate that the lake level in the medieval times (14th – 17th century) was 2 -3 m higher comparing to the normal lake level. Based on these considerations on the lake level change, the ground subsidence appear to be the cause of the sub-bottom archaeological sites distributed in the bottom of Lake Biwa that is deeper than 3m in depth. Various possibilities could be thought for the mechanism of ground subsidence around coastal region of the lake, e.g. tectonic movements by active fault system, liquefaction, and landslides along the coast of Lake Biwa.

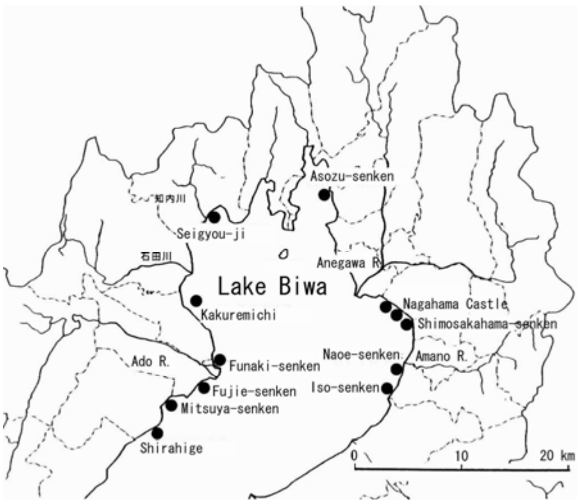

Figure 2. Distribution of sunken villages in Lake Biwa (Hayashi, 2004).

3. THE NAOE-SENKEN SITE

The Chikuma shrine located the east coast of Lake Biwa is the one of the oldest shrine in this region with history for 1000 years and more. This shrine has an old drawing map made in AD 1291 (Fig. 3). Because this map is a copy in 17th century (the original was lost), the exact age have been discussed, however, it is also noteworthy that the coast line of Lake Biwa was backward offshore and the two village, i.e. Nishimura and Kandachi, that were lost at present were illustrated in this map. Thus, the map could be evidence that the land including these villages has subsided from the coastline in the width of about 600 m in the medieval times. This sub-bottom archaeological site is called the Naoe-senken at present (senken means 1000 houses).

The oldest historical document describing the sunken villages is “The catalogue of the Chikuma shrine” written in AD 1597. This document fixed the area of the shrine, and pointed out that the main gate of the shrine, the “Torii”; abnormally exist in the Lake Biwa.

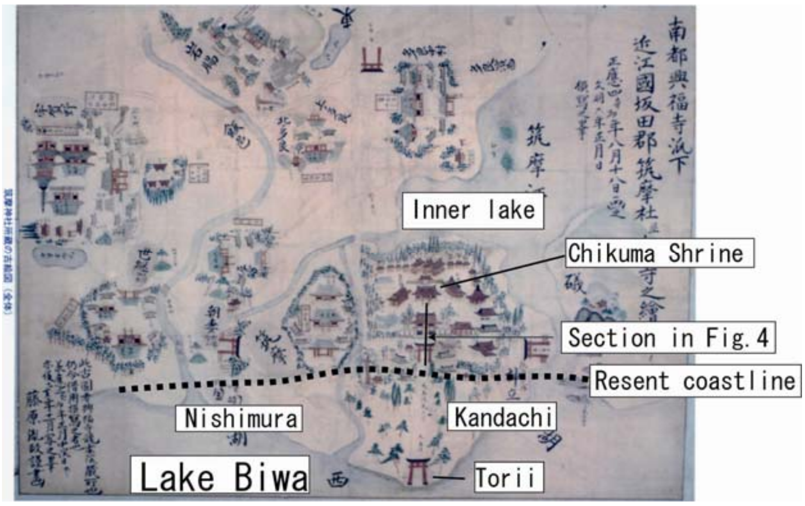

Figure 3. Drawing map of the Chikuma shrine in 1291 (Hayashi, 2004).

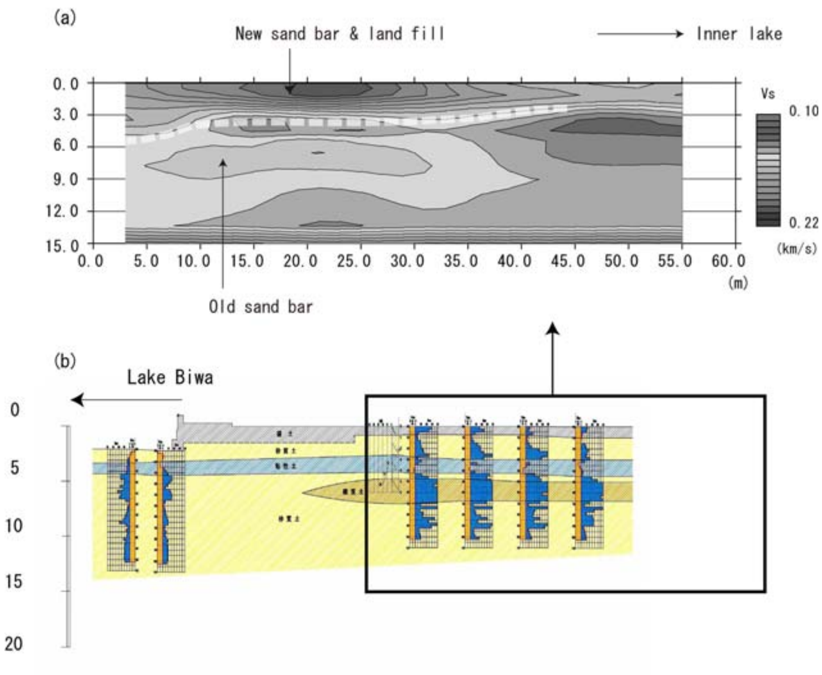

Figure 4. Geologic cross section of the coastal area of the Naoe-senken.
(a) S-wave velocity (*Vs*) cross section.
(b) Cross section made from SWS and boring survey.

3.1 Geologic structure in the coastal region

Fig. 4a shows an S-wave velocity (*Vs*) cross section based on the results of high precision surface-wave explorations in the Chikuma shrine along the section perpendicular to the coastline. The shrine and villages were located on the narrow sand bar between Lake Biwa and the inner lake called the "Irie-naiko" that was reclaimed during 1960's. The area of the right hand side of the cross section with low *Vs*, lower than 150 m/s corresponds to the reclaimed land of the Irie-naiko. In the left hand side of the section, the old sand bar and the new sand bar (embankment) showing higher *Vs* than 150 m/h is interbedded by low *Vs* (less than 150 m/h) beds of about 2m thick, and it has been gently sloping toward Lake Biwa.

As shown in Fig. 4b, this gentle sloping geologic structure was confirmed by Swedish Weight Sounding Tests (SWS) and boring core sampling with Standard Penetration Test (SPT). The intertrappean weak layer of 4 m in depth is loose compacted sand with organic soil. The liquefaction strength ratio (RI_{20}) by cyclic triaxial compression tests for the undisturbed samples form the weak layer (4m in depth) is about 60 % compare with the sample from dense sand in 6 m (center of the sand bar).

The precise radiocarbon ages of the weak layer was determined by acceleratormass spectrometry (AMS). The two-sigma calibrated calendrical date ranges are AD 10-140 for the organic sediments.

3.2 Geology and geomorphology of lake bottom

The geophysical survey of the Naoe-senken region of Lake Biwa was carried out. The survey track of side-scan sonar (SSS) consisted of 26 lines run parallel to the coastline at 10 to 20 m intervals. The survey track of the sub-bottom profiler (SBP) consisted of 13 lines run

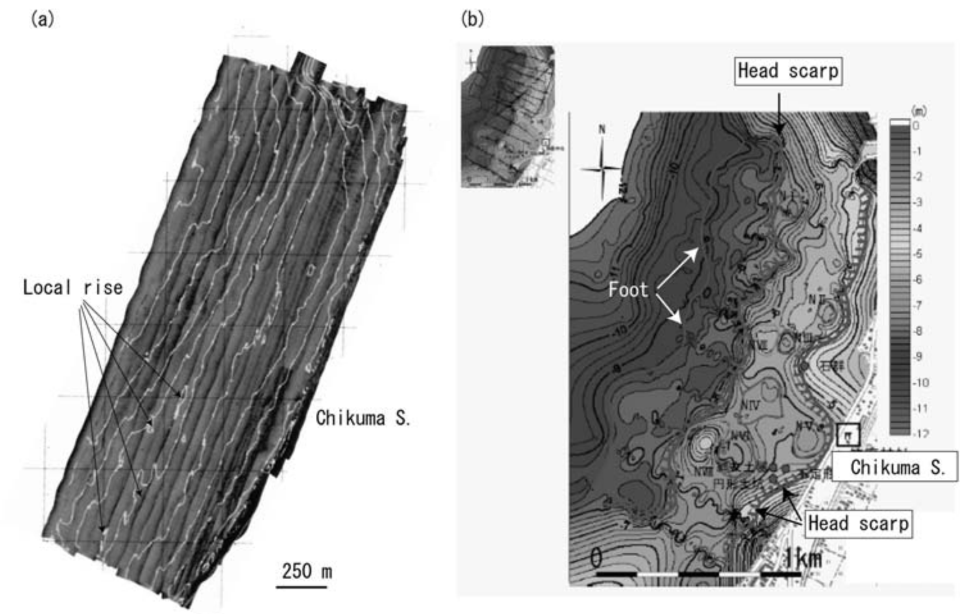

Figure 5. Geophysical survey results in the Naoe-senken.
(a) The bottom image detected by SSS survey
(b) Topography of the first reflection surface by processing on SBP results

perpendicular to the coastline at 10 to 50 m intervals, and 2 lines are in parallel. Although basically smooth bottom topography was detected from coastline to offshore, spotted anomalies on the bottom of the lake, local rise and depression of few meters in diameters are shown in the detailed topographic map produced by side-scan sonar (SSS) data (Fig.5a).

The first highest reflector in the sub-bottom profiler (SBP) images is widely distributed throughout the site and generally gives a clear, strong reflection. Recent sandy lake sediments accumulated between the bottom surface and the first reflection surface. Topographic configuration of the first reflection surface by eliminating the recent sediments is shown in Fig.5b. The parallel cliffs along the coastline indicate the head scarp of submerged landslides.

4. DISCUSSION

4.1 Earthquake in cause

Condensed active fault systems developed around Lake Biwa have caused historical inland earthquake disasters in coastal region of Lake Biwa (Okada and Tougo, 2000). Based on the earthquake-archaeological approach, evidences on liquefaction induced by earthquakes were discovered from sub-bottom archaeological sits in Lake Biwa (Sangawa, 1992). Because the changes of lake level were limited during the medieval age, the ground subsidence induced by a historical earthquake was likely the cause of the Naoe-senken sub-bottom archaeological site. Considering the historical evidences, e.g. the drawing map of the Chikuma shrine, ages of the Naoe-senken were limited from AD 1291 (the age of drawing map) to 1567 (the oldest age of the historical document about the site). Based on the catalogue on the historical earthquake (Usami, 1997), earthquake in AD 1325 (M6.5) is a major potential event as the earthquake with possibility to originate the submerged villages.

This earthquake related to the Yanagase active faults system, and induced serious damages in the northern district of Lake Biwa. The Anegawa earthquake in 1909 (M6.8) was known as similar earthquake related to the same Yanagase active faults system. The liquefaction of ground in coastal region of the lake was caused by the 1909 Anegawa earthquake.

4.2 Liquefaction and landslide at coast

The cyclic shear resistance ratio (F_l) between the maximum cyclic shear stress ratio ($L_{\max}$) and the liquefaction resistance ratio ($R_{\max}$) is an index indicating the possibility of liquefaction (Seed, 1979). Based on the definition, a F_l value less than 1.0 indicates a high probability of liquefaction.

$$F_l = \frac{R_{\max}}{L_{\max}} = \frac{\left(\frac{\sigma_d}{2\sigma_0'}\right)_{20}}{\left(\frac{\tau_{\max}}{\sigma_v'}\right)} \tag{1}$$

Where $R_{\max}$ is defined as the ratio between σ_d and $2\sigma_0'$ required to reach liquefaction at the twentieth loading cycle in the cyclic triaxial test. The maximum cyclic shear stress ratio ($L_{\max}$), was estimated by the conventional method as below.

$$L_{\max} = r_d \cdot k_h \cdot g \cdot \frac{\sigma_v}{\sigma_v'} \tag{2}$$

$$r_d = 1.0 \times 0.015 \times x \qquad x\textbf{:} \text{ Depth (m)} \qquad (3)$$

The results, F_l value should be controlled by the assumption for the horizontal earthquake force (k_h). When the horizontal earthquake force (k_h) of the earthquake in 1325 was assumed 0.3 based on the distribution of damages in the 1909 Anegawa earthquake, the F_l value of intertrappean weak layer would be less than 1.0 (liquefied), and the F_l value of lower sand layer would be greater than 1.0 (not liquefied).

Because the geological structure is gently sloping toward the offshore, the ground around the shrine including the two villages was likely moved into Lake Biwa as a landslide with the slip surface along the liquefied weak layer on the dense sand (the old sand bar). The landslide would travel at least 200 m to offshore since that the sub-bottom profiler imaging revealed the toe structure of the landslide at the bottom of 8 m in water depth.

5. CONCLUSIONS

The investigation results on the Naoe-senken sub-bottom archaeological site suggest that the villages moved into Lake Biwa on the earthquake-induced landslide associated with ground liquefaction caused by the earthquake in AD 1251. Similar case studies were known in Japan, Turkey, and USA. The decline of the ancient Alexandria from 4^{th} century would be caused by the subsidence of the artificial ground at the coast of the Mediterranean Sea induced by earthquakes.

The sub-bottom archaeological sites were distributed offshore of the modern urban regions. Many of the recent artificial ground in this urban region were constructed on the soft natural coastal deposits. Because little attention is paid to basement conditions of fills (embankments), the extensive artificial grounds in urban coastal regions in Japan are subject to a high risk of failure during earthquakes. Thus, the sub-bottom archaeological sites and recent coastal ground in urban region have essentially the same structure of problems, and the sub-bottom archaeological sits in Lake Biwa provide important information for such issues of our modern society.

REFERENCES

Hayashi, H., 2004. The Naoe-senken –study on the sub-bottom archaeological sites in Lake Biwa-, 62 p. (in Japanese)

Huzita, K., Kishimoto, Y., Shiono, K., 1973. Neotectonics and seismicity in the Kinki area, southwest Japan. *Jour. Geosci. Osaka City Univ.*, 16, 93-124.

Okada, A., Tougo, M., 2000. Active faults in Kinki district. Tokyo University Press.

Sangawa, A., 1992. Jishin Koukogaku (The Archaeological Seismology). Chuko Bokks. (in Japanese)

Seed, H.,B., 1979. Liquefaction and cyclic mobility evaluation for level ground during earthquakes. *Jour. Geotech. Eng.*, ASCE, 105, 201-255.

Usami, T., 1997. The historical earthquake catalogue in Japan, Tokyo University Press, 493 p. (in Japanese)