Liquefaction Damage of Harbor Facilities during the 1995 South Hyogo Earthquake

by

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The 1995 South Hyogo Earthquake took several thousand of lives and destroyed momentarily infrastructures which were designed to perform for a long time. Particularly damages of harbor facilities including Kobe Port were almost completely destroyed. Geological hazards occurred on a large scale at many areas too.

This paper describes results of field surveys about damages of harbor facilities and liquefactions mainly in Kobe City, and discusses some about the mechanism and the countermersure.

1. Introduction

The South Hyogo Earthquake with a magnitude of 7.2 on the Richter scale occurred on January 17, 1995. This strong quake had caused severe damages to all infrastructures in a wide area of Kansai region.

The important point to note is that this earthquake was a direct-type occurred at very near location to a city. Therefore the earthquake acceleration was very large both in horizontal and vertical directions, and collapse of buildings and highways. And more its structure were greatly affected.

As a result of this earthquake a lot of geotechnical problems have appeared such as the liquefaction occurred widespreadly in the seaside area of Osaka Bay mainly around Hanshin district. And many harbor facilities were destroyed by this liquefaction.

In this paper we describe mostly about liquefaction problems. At first characteristics of damage are shown in field survey. Secondly the relation-

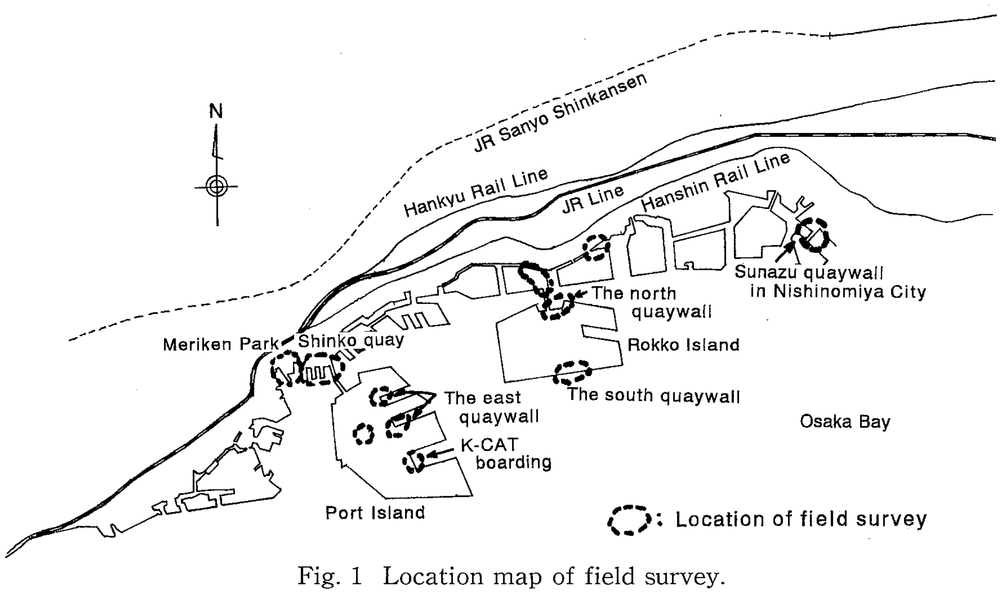

Fig. 1 Location map of field survey.

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ship between liquefaction and topography and geological structure, are shown. Further more mechanism of liquefaction is explained. Finally The effect of liquefaction countermeasure methods is described.

2. Damage Survey

For the survey purposes, a total of six field surveys were carried out in Kobe City.

Figure 1 shows locations of the field survey of harbor facilities. It's clear that these locations are widely distributed throughout Hanshin region.

The major damaged spots are presented in the following.

2. 1 Rokko Island

Photo 1 shows damage of the north caisson quaywall in Rokko Island. At the ground on the right side some cracks run on the surface. A lateral flow of ground is occurred due to liquefaction.

Photo 2 shows a slide of caisson quaywall to the sea side and a scene of destruction of quay surface due to liquefaction. Under pavement a decomposed weathered granite, called "Masado", is accumlated. This soil is colored light brown color and has a large cohesion. Inside, much sand boiling is spread over the surface.

2. 2 Port Island

The moving to the sea side of the east caisson quaywall in Port Island is shown in Photo. 3. The front line of quaywall had moved all alike. From this moving style point of view one may say that the quaywall had been moved by the main shock of this earthquake.

It can be seen in Photo. 4 that the leg of gantry crane is dropped from the driving rail.

2. 3 Meriken Park

Photo 5 shows the destruction of bulkhead on the south side in Meriken Park. This place is considered as a recreation spot for citizens particulary for

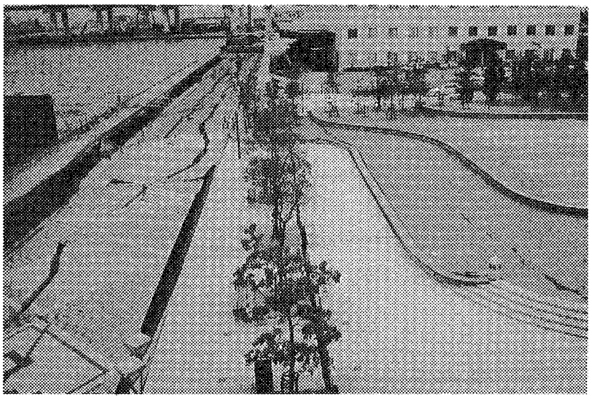

Photo 1 Lateral flow (taken on Feb. 4).

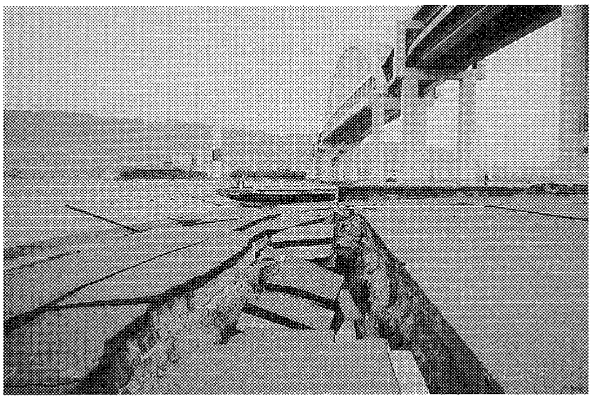

Photo 2 Destruction of quay surface (taken on Feb. 4).

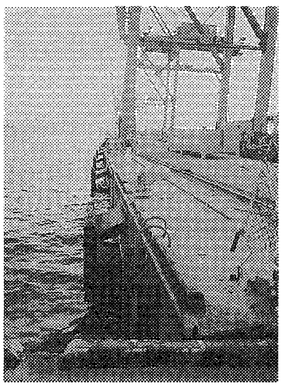

Photo 3 Moving of caisson quaywall (taken on Feb. 12).

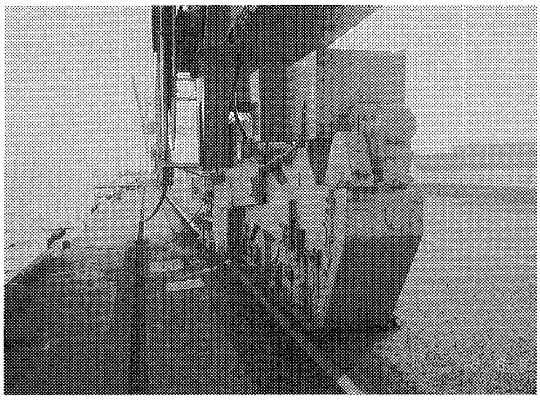

Photo 4 Damage of gantry crane (taken on Feb. 12).

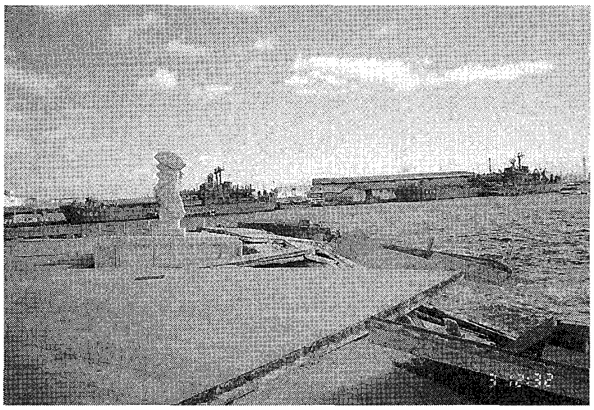

Photo 5 Destruction of bulkhead (taken on Feb. 3).

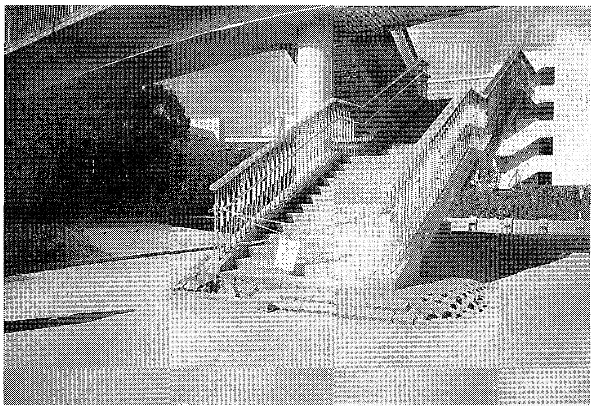

Photo 6 Settlement and rised pile (taken on Feb. 3).

Table 1 *Topographical classification of Kobe City*[1].

direction	districts	geology
north	mountainous	granite, Kobe group, Palaeozoic
↑	hilly and heights	Osaka group, terrace gravel
↓	coastal plains	Alluivial
south	reclaimed lands	reclaimed soil, Alluivial

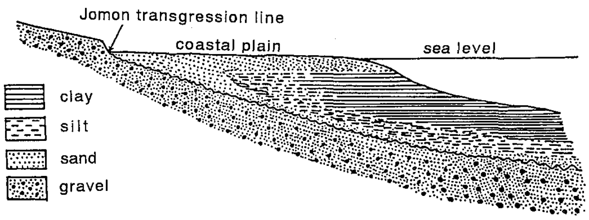

Fig. 2 Geological structure[1].

visitors. The symbol of a sightseeing in Kobe had completely damaged too. The ground under concrete pavement slab has undergone a surface soil Stabilization, because the upper layer under crushed stones is white and is self-supported. it can be regarded that the lower layer had been.

Photo 6 shows a condition on which liquefied the step of pedestrian bridge rised due to settlement. This location is about 200m from one of Photo. 5, and the ground have subsided about 20cm. From this view point one may say that the whole area have subsided.

The fourth survey was carried out on May. 12 four months after the earthquake. On this time a reconstruction work is not done yet.

3. Relationship among damaged area, topography and geology

It was the first time that the intensity 7 on the Japanese intensity scale of 7 was applied on the South Hyogo Earthquake. Area of intensity 7 on the Japanese intensity scale of 7 which released by the Meteoroligical Agency is distributed as a belt which lies between the Rokko mountains in the north side and the Osaka Bay in the south side. Because of this reason it has been said that the characteristics of topography and geology is emphatically related to the transmission mechanism of earthquake waves.

Therefore we can describe the characteristics of topography and geology in the following.

The topographical classification[1] of Kobe City is shown in Table 1. For a ground which looked from the direction for south-north, in the north side the steep Rokko Mountains which formed by granite or by Kobe layer group rises high in the sky, in the south side on the foot of the mountains a gentle alluvial cone is distributed continuously. This alluvial cone is topographic features shaped by weathering colluvium deposits run off as a debris flow from the Rokko Mountains, have accumlated comparatively as large particle deposits as a cobble stone or a gravel. And also a coastal plain formed by the Jomon transgression is spread in the sea side, artificial reclaimed lands are spread along the coast line.

Figure 2 shows the geological structure[1] near the coast line. Between the Jomon transgression cost line, located at 4m above the sea level about ten thousand years ago, and the coast line, it can be regarded that the alluvial low plane is mainly composed of sand and clay layers.

Figure 3 shows the relationship between the old map and the area of 7 on the Japanese intensity scale. The old map presents natural topographical features, in other words, it presents actions of erosion and deposition due to the natural forces. Regarding this matter one can get many informatins from the old map. As Fig. 3 indicates, the distributed area of 7 on the Japanese intensity scale is within 20m above the sea in Hyogo Ward, is within 40m in Tyuo Ward, Nada Ward and Higashinada Ward, and is within about 20m in Ashiya City and Nishinomiya City. Besides it can be regarded that the 7 area is distributed within 5m above the sea, namely anywhere, is distribute in hilly districts or tablelands above the Jomon transgression level. It follows that there is a relation between the damaged area and the thickness of the layer.

Now we look at the damaged area from a different angle in Fig. 3. If one look at a location of a colony early in the Meiji era, a large colony indicated by dots had been developed along waterfront for a reflection of a fishery life in that days, a small colony had been dotted in a little-rise land like a natural levee. And generally, these colonies had been distributed in away from the damaged area. For the reasons mentioned above, it seems that they had chosen a safe area for the purpose of disaster prevention.

Figure 4 shows the result of the piled up the areas of intensity 7 on the Japanese intensity scale on the present topographical map[2]. First, as compared with Fig. 3 from a topographical change point of view, we can see that topographic features of the present map, namely in Fig. 4, is quite different from Fig. 3 regarding the shape of contour lines which, is formed like a rised river bed by the aggradation along Sumiyoshi river, Ashiya river and Shuku river.

Concerning the relation of the area of intensity 7 on the Japanese intensity scale, areas between the Hankyu Railway and Hanshin Railway are included in damaged area. Judging from the above, it can be regarded that the great damage is affected with the spread to the mountain direction along with urbanized areas.

Figure 5 shows the points where liquefactions were occured. the area of intensity 7 on the Japanese intensity scale and the Jomon transgression line are presented together. These liquefaction points are not included within the area of intensity 7 on the Japanese intensity scale, they are located below the Jomon transgression line, they are distributed in the alluvial plain or the reclaimed land. Because these areas are considered as young sedimented areas, the loose grounds are spread.

As shown in Fig. 5, we can verify the topographical factor that make liquefaction easy to happen, 1) a loose ground, 2) a high water table.

4. Judgement of liquefaction for Grain size distribution

Results of grain size analysis of sand boiling sample obtained from in situ are shown in Fig. 6. Because sand boiling is a soil which spouted and accumulated above the ground with waters, we must be care that the grain size distribution for laboratory test is different from which in the field.

The No. 2 sand boiling that picked up at the school ground in Port Island includes some big gravels with the biggest diameter of 19mm of the particle size. This fact indicates that a very large water pressure has occurred when the earthquake was started.

The grain size accumulation curve shown in Fig. 7 includes all curves shown in Fig. 6 can be used as a judgement criterion of liquefaction[3] as established by the Harbor Office, the Ministry of Transport. If a curve is included within the range A, the soil is judged as a soil with a big possibility of liquefaction occurence. If a curve is included within the range B_f or B_c, the soil is judged as a soil with possibility of liquefaction occurence.

As a result of laboratory test for the sand boiling, it can be regarded that all soils are included within the range A.

In Fig. 7, the No. 6 soil at the north quaywall in Rokko Island is not a sand boiling. The grain size accumulation curve is distributed in wide range. So far as the grain size distribution is concerned, it can be used in judging weather liquefaction may

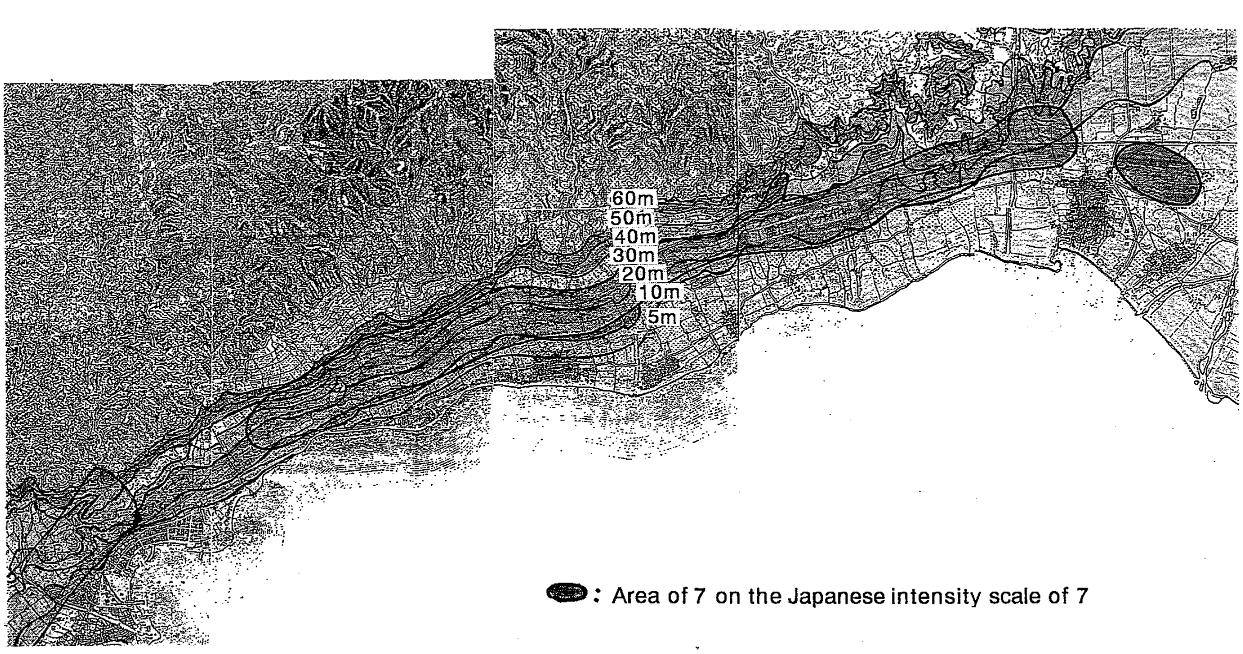

Fig. 3 Damaged area on the old map.

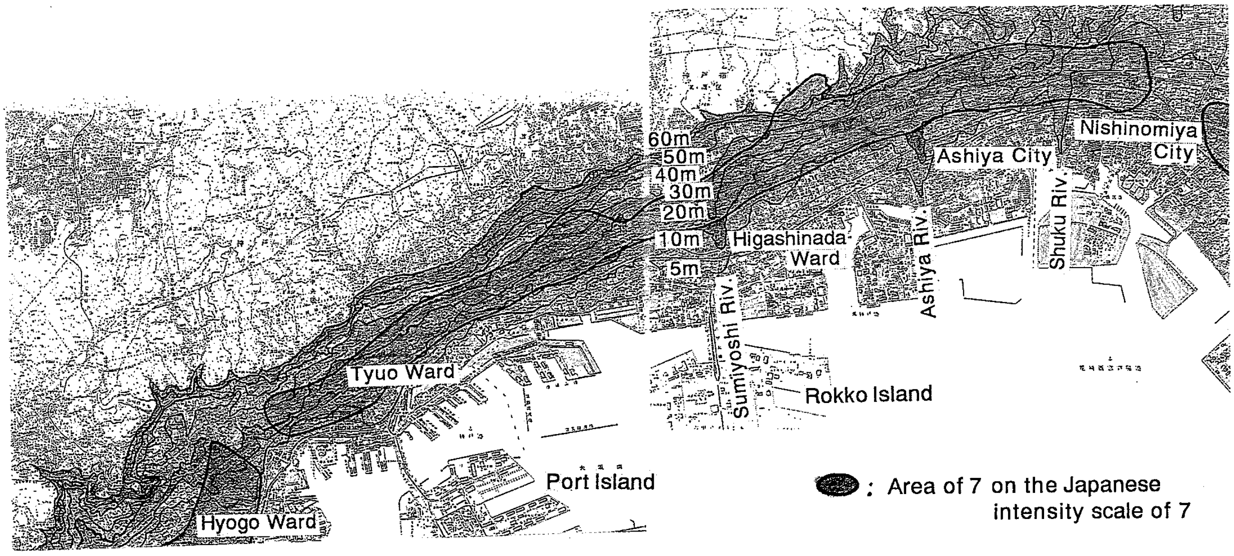

Fig. 4 Damaged area on the present map.

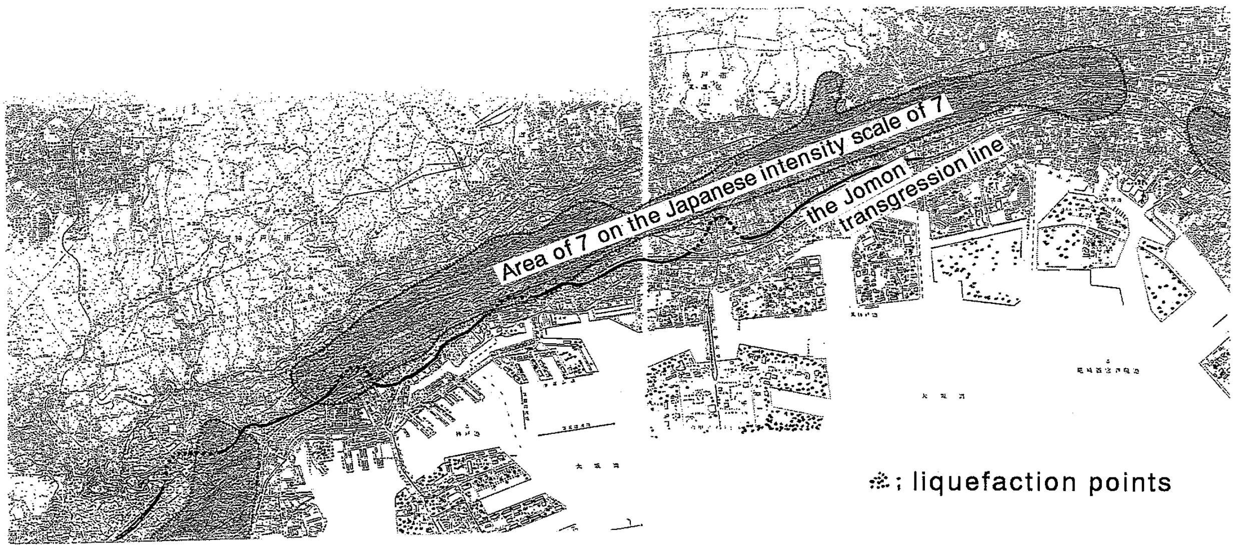

Fig. 5 Relationship the liquefaction area and the Jomon transgression line.

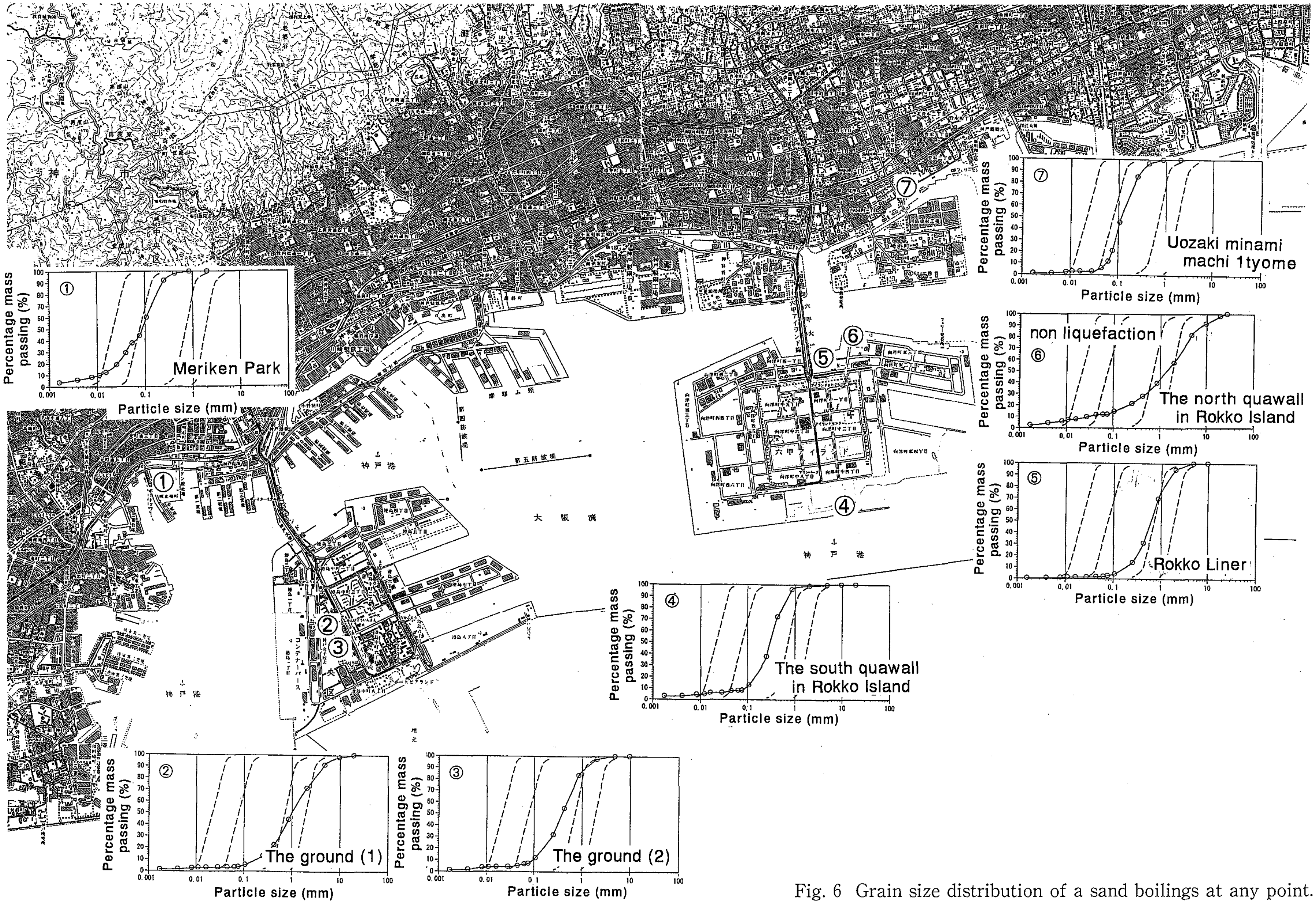

Fig. 6 Grain size distribution of a sand boilings at any point.

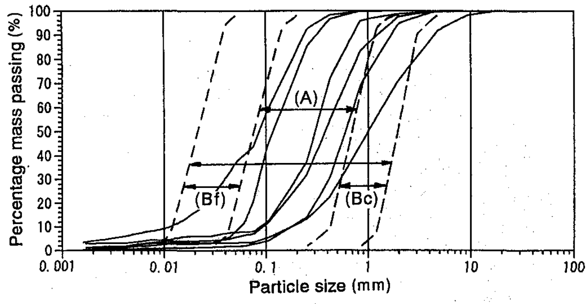

Fig. 7 Grain size distribution of a sand boiling.

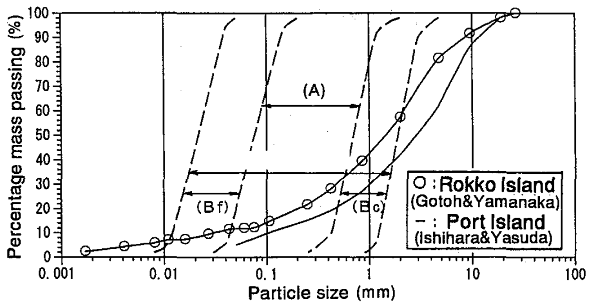

Fig. 8 Grain size distribution of a reclimed material (comparing our data with the data of K. Ishihara & S. Yasuda[4]).

occur or not. But some sand boiling have been spreaded on the surrounding area, and there were some traces of liquefaction too.

A decomposed weathered granite origined at Rokko Mountains have been used in reclaiming artificial islands like Rokko Island and Port Island. As Fig. 8 indicates, this soil has a good grain size distribution and has a cohesion to some degree, and it has been said as a suitable soil for reclimation purposes material because it has a good resistance against liquefaction. Eventhough liquefaction have been occured widespreadly in these artificial islands. We can say that some analysis are left for future.

5. Destructive mechanism of the caisson quaywall

Many harbor facilities have got grave damages by this earthquake. Because Kobe City is a harbor town in particular, this earthquake caused many influences on a social and a economical activity. The gantry crane on caisson quaywall was almost completely destroyed as shown in Photo. 4, and this damage have made almost loading and unloading

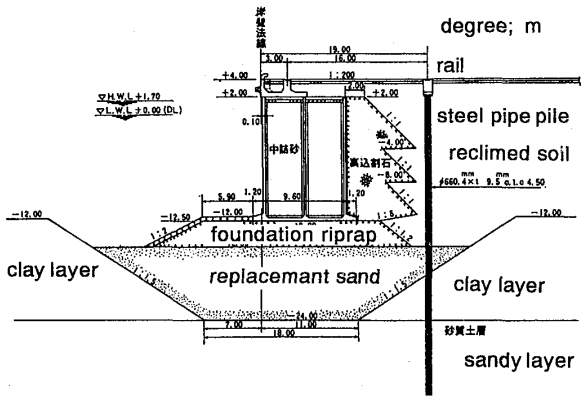

Fig. 9 A sectional diagram of the caisson quaywall[5].

works to be impossible for a long time.

The destructive mechanism of the damaged quaywall can be explained by looking at Fig. 9 which shows the cross sectional diagram[5] of the caisson quaywall at the Port Island container berth. The part under the caisson was substituted by a decomposed weathered granite in stead of the weak marine clay similar to the reclaimed soil, and the part behind the caisson was back-filled by rubbles. Under the rail at seaside, steel pipe piles were placed.

An estimated diagram for the damaged conditon is shown in Fig. 10. As a result of our field surveys, we noticed that most of the caissons were bent forward the sea side, and uniformly moved forward. Because of the moving of the caissons, the behind ground had sunk about 1~2m. And sand boilings were accumulated on the subsidenced ground and the behind area from the ground.

For the reasons mentioned above, conditions and a scale of the earthquake, and the destructive mechanism of the caisson quaywall can be judged as follows,

• At first the caisson is lifted by the seismic acceleration which was beyond the expectations, which is in the vertical direction in this case, the friction force between the base of the caisson and the foundation riprap is lost, and the caisson is moved in forward direction due to a active earth pressure of the behind reclimed soils.

• Because of the moving of the caisson and occurrence of the liquefaction, the behind ground

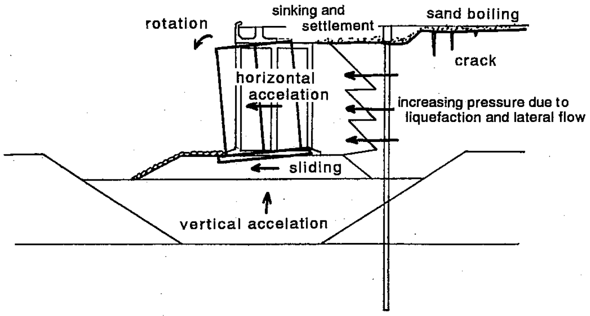

Fig. 10 Estimated diagram for the damaged condition.

flows in lateral direction and some cracks occur in the ground.

On the other hand, it may be that the caisson was moved by the increasing pressure due to the liquefaction and the lateral flow. But the seismic acceleration of this earthquake is very large, and is a direct type earthquake which occurs in a short period of time. By considering the a appearance process of liquefaction, it is difficult to think that the pore pressure rises at a short time like this shake and the liquefaction occurs later. Therefore it seems reasonable to suppose that the most important external force, which moved the caisson, is the inertia force due to the seismic acceleration.

6. Effect of liquefaction countermeasure

Considering the effect of liquefaction countermeasure in Port Island, some liquefaction countermeasure methods or some accelerated consolidation methods were carried out mainly at the residential section in the Island.

Figure 11 shows the relationship between the area of these countermeasure methods[6] and the liquefaction distribution area[7] based on the survey of the Geographical Survey Institute, Ministry of Construction. In areas which constructed by the rod compaction method as a liquefaction countermeasure, there is few area of liquefaction, this effect is obviously. And in the area which done by the sand- drain method as an accelerated consolidation method, it is noticed that there is some effect of liquefaction countermeasure. On the other hand, in area of no liquefaction countermeasure liquefactions widely occured, from here we can observe the effect of these soil improvement

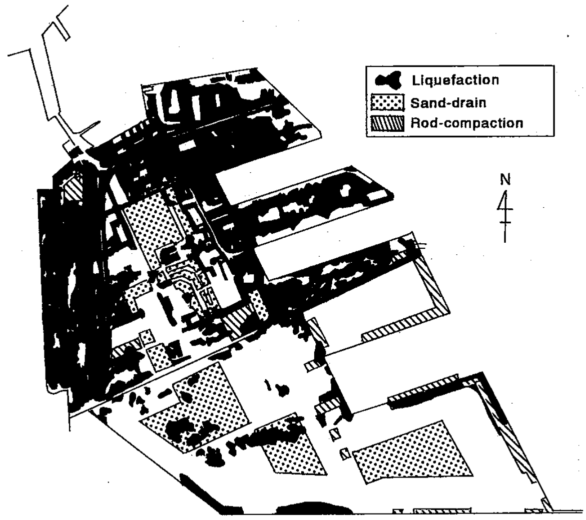

Fig. 11 Distribution of liquefaction in Port Island.

methods and techniques and their importance in liquefaction reduction.

7. Conclusions

In this papar we have described the damage conditions and the destructive mechanisms of the harbor facilities only. The cause of the damge is now under investigation, enough data to conclude the cause have not been published yet. Therefore in a condition like this, we could write only an outline and a qualitative explanation on the South Hyogo Earthquake. But we should notice that the grain size distribution method to make a judgment of liquefaction must be reconsider once more. And it must be realized that the liquefaction have been reduced by using some soil improvement method and techniques.

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