STUDY ON EARTHQUAKE-PROOF REINFORCEMENT OF BREAKWATER IN FISHING PORT TO NANKAI EARTHQUAKE

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***ABSTRACT*:** The Nankai Earthquakes, of which epicenters are at the Nankai Trough in the offshore in the Tosa Bay, has occurred repeatedly every 90-150 years. The Japan government officially announced that the earthquake will occur with the 50 per cents of probability within the coming 30 years, and with the 80 per cents of probability within 50 years.

According to the "The second earthquake assessment of Kochi Prefecture", it is assumed that the Nankai Earthquake ground motion has maximum acceleration 400 galls or more, long period wave of 2-3 seconds, and continues for about 90 seconds. The height of the maximum tsunami is 6-10 meters. Kochi Prefecture has approximately 270 km coastal-line on which 130 fishing ports are scattered and 69,000 people live in this area. And the fishing ports will be expected to suffer from the serious damage by the earthquake motion and by the tsunami caused by Nankai Earthquake (Okabayashi, Tagaya, Takeuch and Ono, 2004).

The fishing ports are very important as the life base of local populace for the relief activity, restoration-reconstruction and business continuity plan. The fishing ports are desired to be maintain the function at least by the sectional reinforcement against the earthquake motion and tsunami by Nankai Earthquake. This research was executed for the Kaminokae Fishing Village, where is the typical district of the local fishing port in Kochi Prefecture. The prediction of liquefaction was performed based on Momentary Deformation Modulus(MDM) Method. The economic construction methods such as by the replacement methods by the light weight treated soil and by the driven sheet pile, which can improve the earthquake-resistant, are discussed.

As a result, 1)In Kaminokae Fishing Village the strong possibility of liquefaction in most area was observed. 2)The replacement methods by the light weight treated soil and the driven sheet pile can improve the earthquake-resistant for the fishing port.

KEYWORDS: Nankai Earthquake, prediction of liquefaction, improve the earthquake-resistant

1. INTRODUCTION

In Kochi Prefecture, the fishing ports are desired to maintain the function of port at least by the simple sectional reinforcement against the earthquake motion and tsunami by Nankai Earthquake. This research was executed to the Kaminokae Fishing port, where is one of the typical fishing port in Kochi prefecture. The prediction of liquefaction was performed based on Momentary Deformation Modulus (MDM) Method. The economic construction method such as by the replacement of methods of the light weight treated soil and by the driven sheet pile, which can improve the earthquake-resistant, are discussed.

2. PREDICTION OF GROUND LIQUEFACTION

The points of the liquefaction prediction in Kaminokae Fishing Village are shown in Fig.1. For the detailed estimation of liquefaction, the four borings (Nos. A-D) to reach to the bedrock were performed in addition to existing 23 borings to

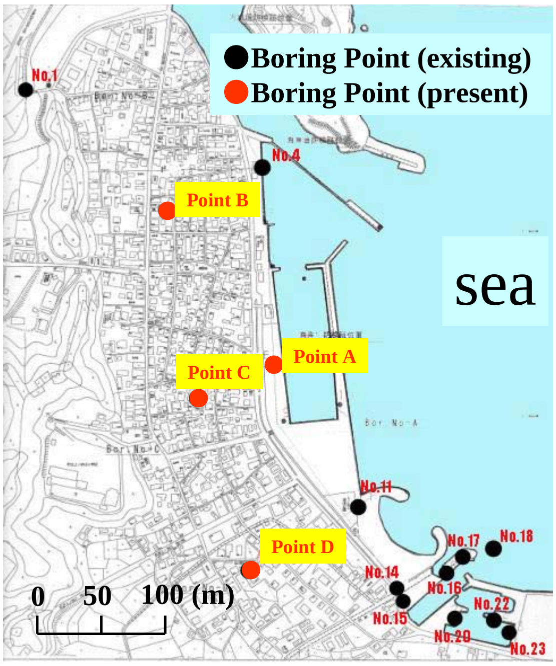

Fig.1 Soil investigation point at Kaminokae

confirm the soil strata for doing the necessary soil test for the liquefaction prediction. The geological section along the coastline was made based on the result of the survey, as shown in Fig.2. The strata consist of six layers of which the soil test results are shown in Table 1. The geologic column and the distribution of N value of point A are shown in Fig.3.

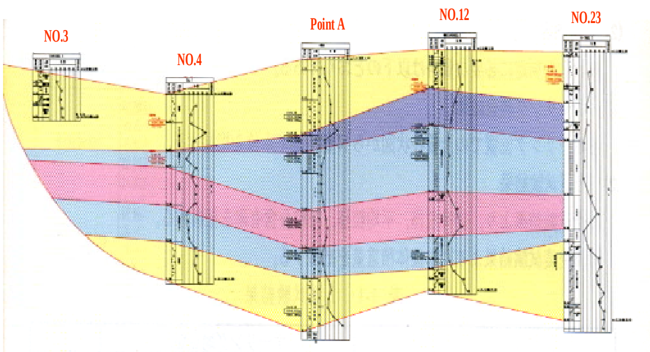

Fig.2 Profile of soil strata

Table 1. Result of soil test

Stratum	Name	Result of Soil Test		
I	Sandy gravel with Silt	FC	%	13.475
		D_{10}	mm	0.0238
		D_{50}	mm	4.2969
		I_p	—	9.3
II	Sand	FC	%	28.8
		D_{10}	mm	0.046
		D_{50}	mm	0.129
		I_p	—	
III	Silt	FC	%	84.4
		D_{10}	mm	0.001
		D_{50}	mm	0.0137
		I_p	—	25.15
IV	Volcanic ash	FC	%	38.7
		D_{10}	mm	0.0042
		D_{50}	mm	0.1096
		I_p	—	-
V	Silt	FC	%	96.2
		D_{10}	mm	0.001
		D_{50}	mm	0.0049
		I_p	—	28.25
VI	Sandy gravel with Silt	FC	%	22.4
		D_{10}	mm	0.0078
		D_{50}	mm	1.4828
		I_p	—	8.35

FC : Rate of fine-grained soil D_{10} : Effective grain size
D_{50} : Average grain diameter Ip : Plasticity index

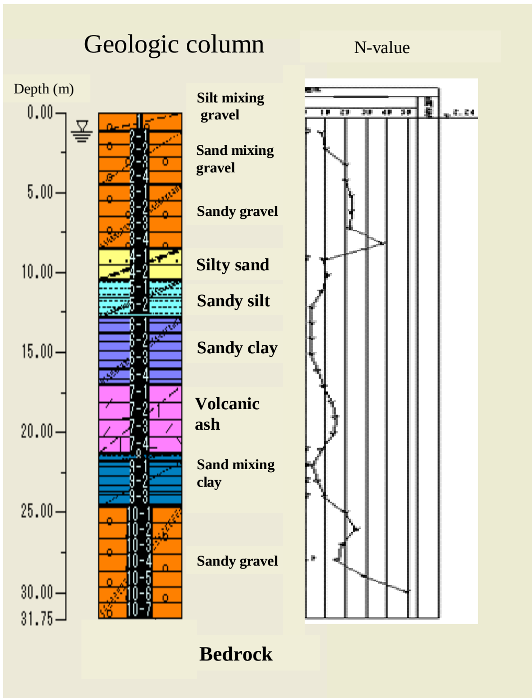

Fig.3 Boring log (Point A)

In addition, the frozen undisturbed samples were taken in the layers at point A to perform the cyclic triaxial compression test and to examine the possibility of liquefaction (Okabayashi, Tagaya, Mizuta and Nishida,2006). The samplings of soil were done at the following depths:

1). 8.5-10.5m at the second layer (sand)

2). 10.8-17m at the third layer(silt)

3).21.8-24.0m at the fifth layer (silt)

2.1 Momentary Deformation Modulus Method

In Simplified Prediction Method, the amplification and the damping of the earthquake wave by the soil structure were not considered（Japan Road Association2002 ; Fishing Port Fishery Society2003). The liquefaction evaluation was made by using MDM Method from the view point of the accuracy for the liquefaction evaluation. The seismic response analysis was performed by the one-dimensional total stress seismic response analysis by using MDM Method(Chubu E. P. Co. Inc. 2002; Kumazaki, 2003 ; Takenaka and Okabayashi, 2004). In MDM model, the strain dependency on the shearing rigidity G and the damping coefficient h as the nonlinear model parameter of each stratum are considered to a higher strain level. The soil parameters on the dynamic deformation characteristics for each stratum were adopted from the existing basic data of Public Works Research Institute(1982) and Ministry of Transport, Ports and Harbors Bureau (1997). The energy dissipation was considered for the engineering bedrock which was half space ground and consecutive nonlinear analysis is performed in this analysis.

The liquefaction of each stratum was evaluated by the rate of liquefaction resistance FL value, and the liquefaction potential in plane was evaluated by PL value. The rate of liquefaction resistance FL is calculated by Eq. 1 to the soil layers, which need the evaluation of liquefaction. The soil layer, which FL value is 1.0 or less, has the possibility of liquefaction.

$$F_L = R/L \qquad (1)$$

where:

F_L: rate of liquefaction resistance

R: dynamic shearing strength ratio

L: shearing stress ratio during earthquake

Liquefaction potential PL value is obtained by Eq. 2 from the underground water level to GL-20m in depth.

$$PL = \int_0^{20} (1 - F_{L,Z})(10 - 0.5z)dz \qquad (2)$$

where : $F_{L,Z}$: rate of liquefaction resistance in depth z ($F_{L,Z}$ =1 for $1 \leq F_{L,Z}$) z: depth(m)

2.2 Calculation of shearing stress ratio L during earthquake

Fig.4 shows the input seismic wave used for the seismic response analysis. This seismic wave is a wave profile on the engineering bedrock (N value : 50 or more) at Kaminokae area based on “The second basic study of earthquake in Kochi Prefecture”.

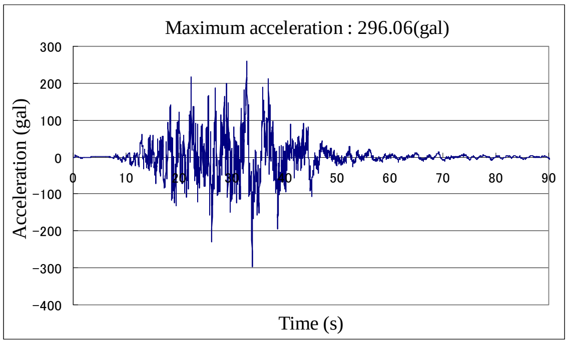

Fig.4 Base seismic wave

2.3 Calculation of cyclic shearing strength ratio R

In the calculation of the shearing strength ratio, the results of cyclic triaxial test conducted by the laboratory liquefaction test or the conventional method for liquefaction strength Simplified Prediction Method were used. One example of the result of cyclic triaxial test is shown in Figs.5~6.

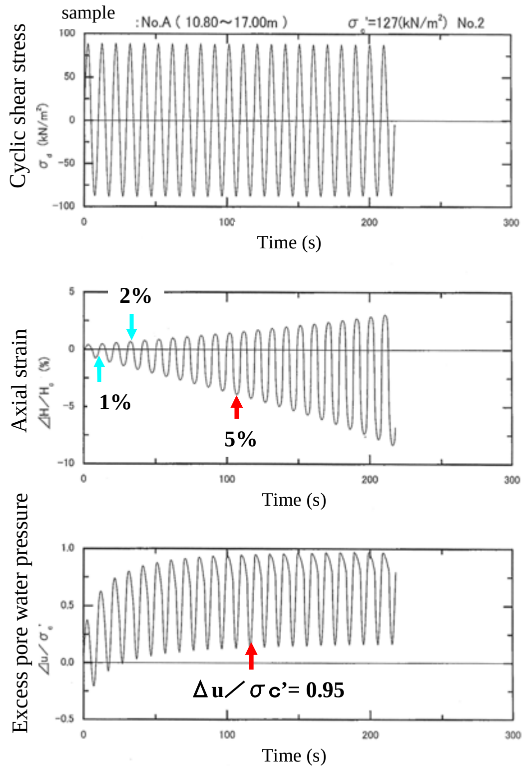

Fig.5 Example of the result of cyclic triaxial test

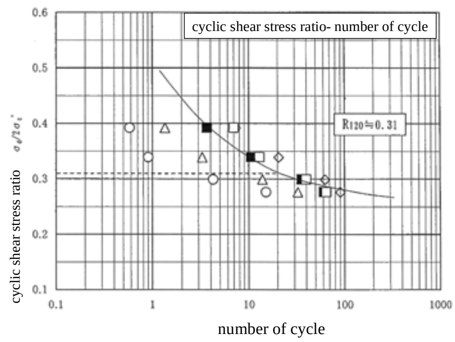

Fig.6 Test result of liquefaction strength

The example of the liquefaction evaluation result by MDM method at point 23 is shown in Fig.7.

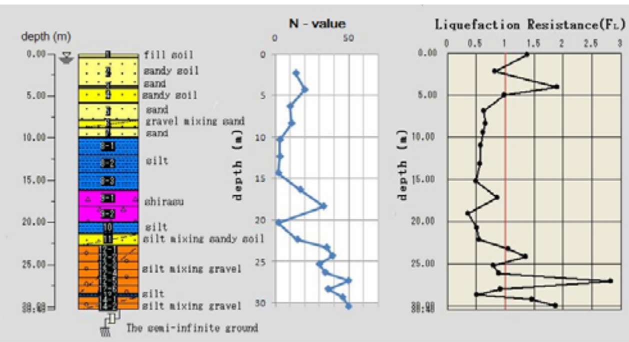

Fig.7 Example of the liquefaction evaluation result by MDM method at point 23

3. MAKING OF HAZARD MAP

The liquefaction hazard map in this area was made as shown in Fig.8 by P_L value previously described. In this area, the strong possibility of liquefaction is observed in most area. It is understood that the liquefaction potential becomes small with leaving from the coastline.

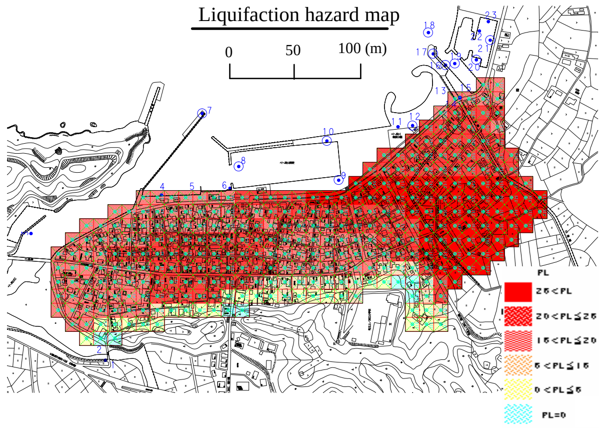

Fig.8 Liquefaction hazard map

4. EARTHQUAKE RESISTANCE OF FISHING PORT QUAY AND COUNTERMEASURE'S ANALYSIS

4.1 Analytical Model and Analysis Method

Dynamic FEM analyses were performed for the tide barrier of the Kaminokae district, and earthquake resistance was examined to the Nankai earthquake. Fig.9 shows the section of the tide barrier as an analytical model.

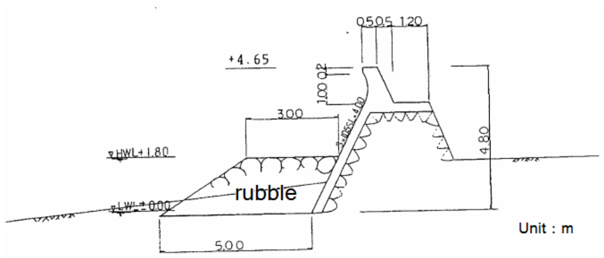

Fig.9 Section of Breakwater as an analytical model

The interaction analysis program of ground-structure " Super FLUSH/2D" was used for these analyses. The analysis method is equivalent linear analysis by total stress method. To examine the dynamic behavior of the ground, the upper ground were modeled from the bedrock. The boundary conditions at the bottom and the sides are viscous boundary, and the energy transmission boundaries, respectively. Fig.10 shows the cross section and strata profile for the analytical model. The material constant is shown in Table 2. The seismic wave used for the analysis is same as shown in Fig.4.

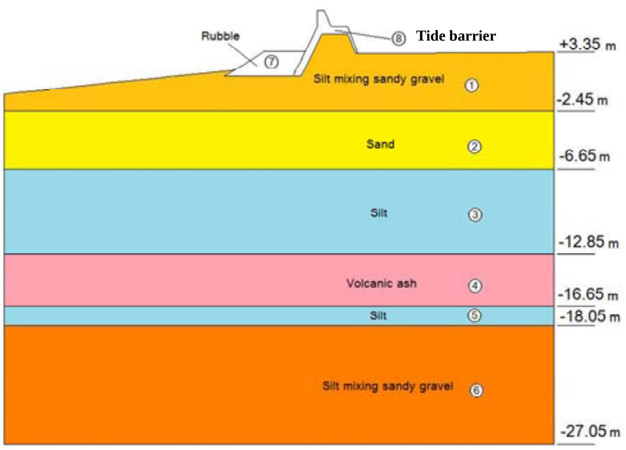

Fig.10 Cross section and stratum profile for analytical model

Table 2 . The material constant

Material number	Material	Poisson's ratio	Unit weight (kN/?)	Elastic shear coefficient (kN/㎡)	Damping constant (%)
1	Silt mixing sandy gravel	0.42	19	56,000	3
2	Sand	0.45	18	66,300	4
3	Silt	0.47	17	69,300	4.5
4	Volcanic ash	0.46	18	89,000	4
5	Silt	0.47	17	108,000	4.5
6	Silt mixing sandy gravel	0.42	19	150,000	3
7	Rubble	0.4	20	45,000	3
8	Concrete	0.35	23	52,000	3

4.2 Analytical Cases

Table 3 shows the analytical cases. An analysis for the case of the original ground, two cases of light weight treated soil and two cases of sheet pile were executed.

Table 3. Analysis Cases

Case	Improvement method	Improvement condition	
Ⅰ	Unimprovement	original ground	
Ⅱ	Light weight soil	width	5m
Ⅲ			10m
Ⅳ	Sheet pile	length	22.2m
Ⅴ			22.2m

Fig.11 shows the time-history of the horizontal response displacement on node A(at the land side shoulder of tide barrier) as shown in Fig.12. Fig.12 shows the horizontal displacement at the time of the maximum horizontal displacement at node A. Maximum displacement at node A is approximately 25cm. The horizontal displacement grows larger with distance from the tide barrier to the land side.

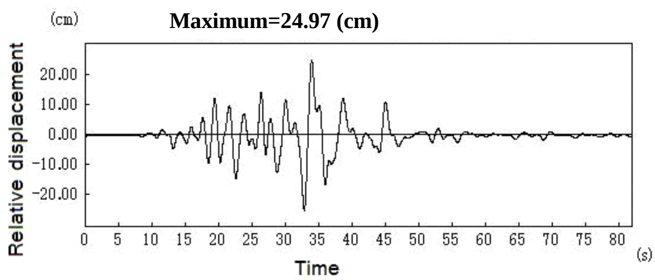

Fig.11 Time-history of the horizontal displacement at node A (Case Ⅰ)

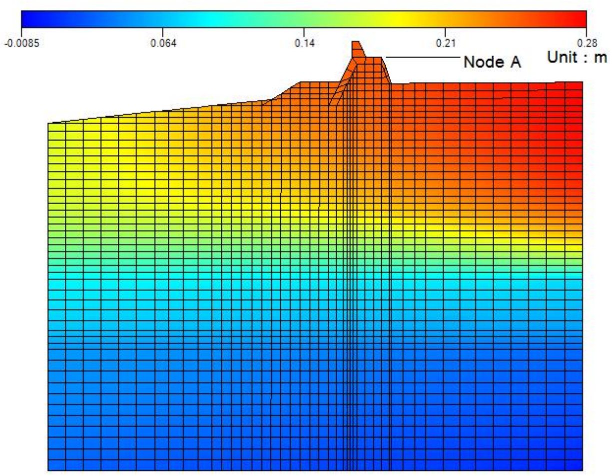

Fig.12 Horizontal displacement at the time of the maximum displacement at node A (Case Ⅰ)

4.3 In case of the light weight treated soil

The improvement of earthquake resistance when the backfill of the tide barrier was replaced with the light weight treated soil was analyzed. The width of the improvement has been changed to 5m and 10m as shown in Fig.13. The material constant of the light weight treated soil is shown in Table 4.

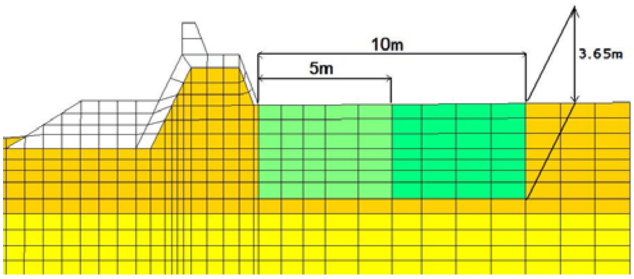

Fig.13. Improvement area by the light weight treated soil

Table 4 . Material constants of light weight treated soil

Material	Poisson's ratio	Unit weight (kN/?)	Elastic shear coefficient (kN/㎡)	Damping constant (%)
Light weight soil	0.1	11.1	1,500	3

Fig.14 shows the time-history of the horizontal displacement at node A. The maximum horizontal displacement at node A has decreased to about 16cm with the width of the 5m improvement. Fig.15 shows the horizontal displacement at the time of the maximum horizontal displacement at node A.

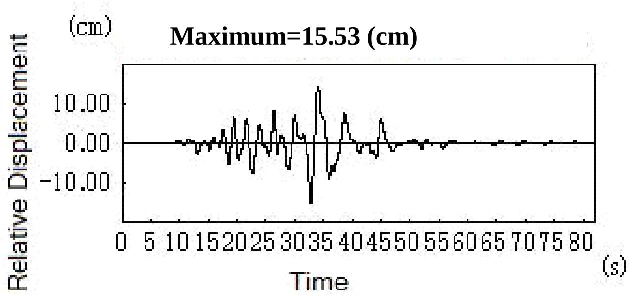

Fig.14 Time-history of the horizontal displacement at node A (Case II)

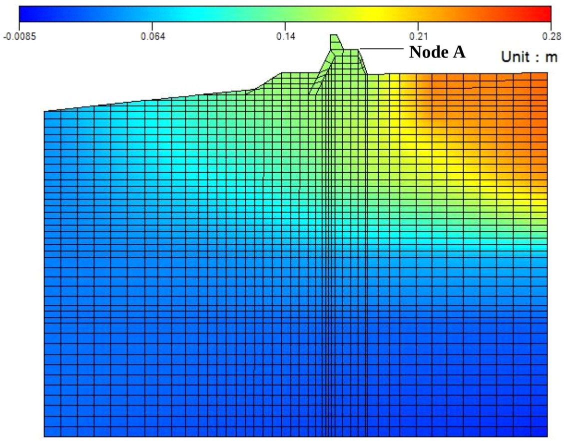

Fig.15 Horizontal displacement at the time of the maximum displacement at node A (Case II)

Fig.16 shows the time-history of the horizontal response displacement at node A. The maximum horizontal displacement of node A has decreased to about 4cm with the width of 10m improvement. Fig.17 shows the horizontal displacement at the time of the maximum horizontal displacement at node A.

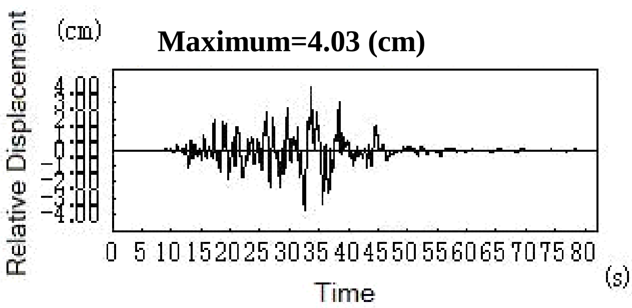

Fig.16 Time-history of the horizontal displacement at node A (Case III)

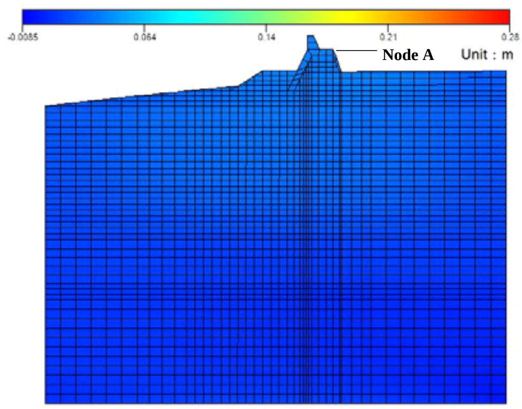

Fig.17 Horizontal displacement at the time of the maximum displacement at node A (Case III)

The maximum horizontal displacement of node A decreased to about 4cm with the width of the 10m improvement. Therefore, it has been understood to achieve an enough effect of the improvement if the width of the improvement is adjusted to about 10m.

4.5 In case of Sheet pile

Two cases of seismic analysis when Sheet pile was installed from the toe of the tide barrier to a hard layer of surface Shirasu (material number 4) and silt mixing sandy gravel (material number 6) that was a comparatively hard layer were performed. Fig.18 shows the arrangement of sheet pile. Table 5 shows the material properties of the sheet pile.

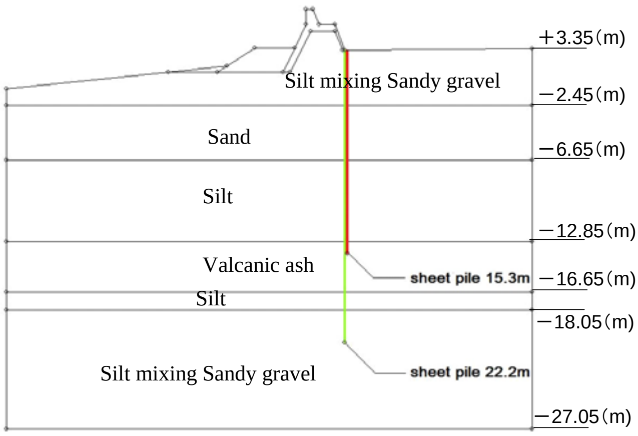

Fig.18 Arrangement of sheet pile

Table 5. material properties of the sheet pile

Material	Poisson's ratio	Unit weight (kN/?)	Elastic shear coefficient (kN/㎡)	Sectional area (㎡)	Moment of inertia (m?)	Damping constant (%)
Sheet pile	0.3	87.5	129,800,000	0.0226	0.000567	3

Fig.19 shows the horizontal displacement at node A in case of the short sheet pile. Fig.20 shows the horizontal displacement at the time of the maximum horizontal displacement at node A. The maximum horizontal displacement of node A is about 4cm.

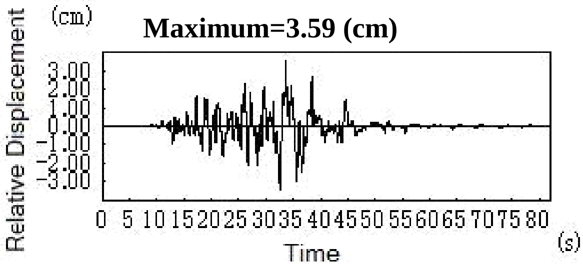

Fig.19 Time-history of the horizontal displacement at node A (CaseⅣ)

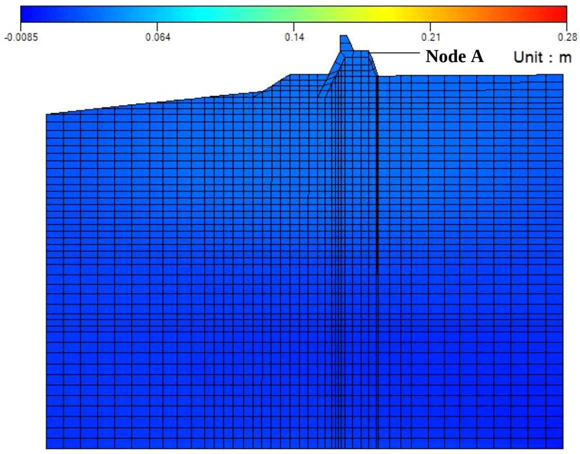

Fig.20 Horizontal displacement at the time of the maximum displacement at node A (CaseⅣ)

Fig.21 shows the horizontal displacement at node A in case of long sheet pile. The maximum displacement at node A is about 4cm. It has been understood that the effect of the improvement hardly changes. The horizontal displacement is similar to Fig.20, and almost changeless, too. Therefore, the change was hardly seen in an earthquake-resistant effect of the difference of the sheet pile depth.

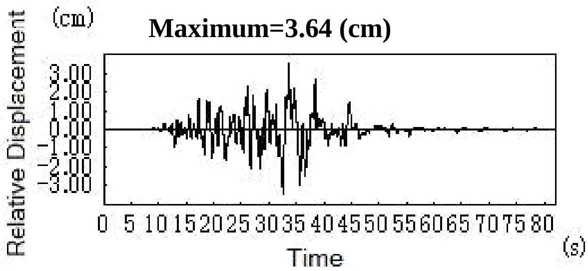

Fig.21 Time-history of the horizontal displacement at node A(CaseⅤ)

Table 6. Maximum relative displacement at node A

Case	Maximum relative displacement at node A
Ⅰ	24.97cm
Ⅱ	15.53cm
Ⅲ	4.03cm
Ⅳ	3.59cm
Ⅴ	3.64cm

Table 6 shows the comparison of horizontal displacement at node A. From this table, it has been understood to achieve an enough effect for the light weight treated soil when the improvement area is about 10m, and to achieve an enough effect for the sheet pile when the placing depth of the sheet pile is short.

5. CONCLUSION

The following conclusion were obtained ;

1)The Kaminokae Fishing Village, where is the typical district has observed the strong possibility of liquefaction.

2)The replacement methods by the light weight treated soil and the driven sheet pile can improve the earthquake-resistant for the fishing port.

And the following future problems have been obtained;

1) It is necessary to investigate the economic construction method which can improve the earthquake-resistant for the fishing ports in kochi prefecture.

2)It is thought that it will be necessary to make the hazard map in the fishing villages, and to apply it to "Tsunami evacuation plan" and the efficient effective hardware preparation plan in the future.

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