PREDICTION METHOD OF LIQUEFACTION AT FISHING VILLAGE IN KOCHI PREFECTURE BY NANKAI EARTHQUAKE

Kojiro OKABAYASHI, Kozo TAGAYA
Kochi National College of Technology
Katsuya MIZUTA
Daiichi Consultant Co.Ltd.,
Tadashi NISHIDA
Oceanographic office, Kochi Prefecture

ABSTRACT**:** Nankai Earthquake has occurred at the interval of 90-150 years. The probability is said to be M8.4, with 50% within 30 years and with 80% within 50 years. There is a big possibility of liquefaction because of the loose sand at the coastal zone of the Kochi Prefecture. It is required to investigate the liquefaction potential as accurate as possible for the evacuation plan. To accurately examine the evaluation of liquefaction potential, the cyclic triaxial test by undisturbed samples were executed.

This research was executed to the Kaminokae Fishing Village, where is the representative model district, and to other places. The simulated earthquake at the bedrock, which was made on the assumption of magnitude 8.4 and the hypocenter on the Nankai Trough was used.

The prediction of liquefaction was performed based on "Guidance of Facilities Design of Fishing Village and Fishery (version 2003)", "Simplified Prediction Method (SPM) of Specification for Highway Bridges(version 2002) " and "Momentary Deformation Modulus Method (MDM)".

The conclusions of this study are : (1) Guidance of Facilities Design of Fishing Village and Fishery gives strong liquefaction potential, (2) SPM gives the stronger liquefaction potential compared with MDM, and (3) Simplified Prediction Method of Specification for Highway Bridges is recommendable as the " Basic guideline of liquefaction evaluation method for Fishing Village and Fishery " .

KEYWORDS: Liquefaction, Nankai Earthquake, MDM method

1. INTRODUCTION

The 130 fishing ports are scattered at the coast of Kochi Prefecture, where 69,000 people in the 109 villages live in this area, and will be expected to be suffered from the serious damage of the earthquake motion and the tsunami by Nankai Earthquake. The purpose of this study is to predict the ground liquefaction potential by Nankai Earthquake, as a part of the plan of basic policy for evacuation. This paper focuses the prediction method of grand liquefaction. The liquefaction prediction by the three detailed methods was performed for the Kaminokae district in Nakatosa-cho to compare these three methods. Then, the prediction method of the ground liquefaction in the fishing village was proposed. Moreover, the hazard map of the ground liquefaction in this area was made.

2. PREDICTION METHOD OF GROUND LIQUEFACTION

The characteristics of Hanshin-Awaji Earthquake on the ground liquefaction which occurred on January 17, 1995, are as follows to include these items to liquefaction prediction method:

1) The liquefaction was generated in the large shore reclaimed area, where was composed of decomposed granite including a wide-range particle size with gravel.

2) Liquefaction was generated at the soil of the rate of fine-grained particle 35% or less.

3) The lateral flow occurred in the large area with the generation of liquefaction.

"Guidance of Facilities Design of Fishing Village and Fishery (version 2003)" and "Simplified Prediction Method (SPM) of Specification for Highway Bridges (version 2003)" were revised based on the abovementioned characteristics.

The points of the liquefaction prediction in Kaminokae district 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 confirm the soil strata to do the necessary soil test for the liquefaction prediction. The geological section along the cost line

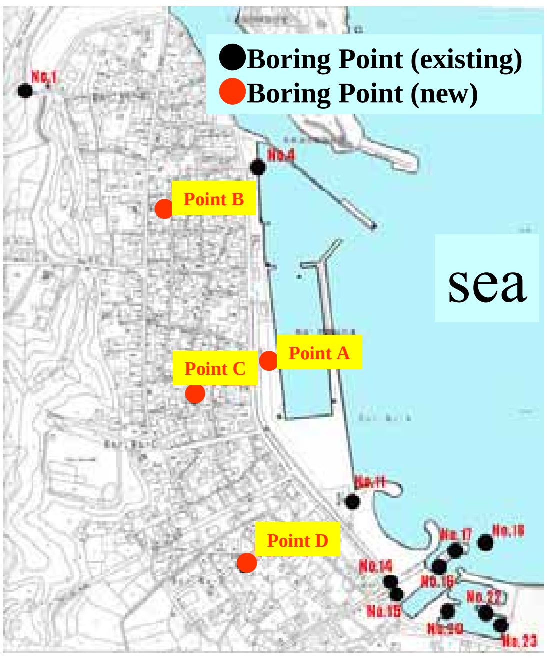

Fig.1 Investigation point at Kaminokae

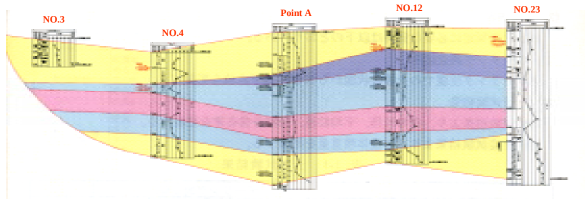

Fig.2 Stratum profile

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
		Ip	—	9.3
II	Sand	FC	%	28.8
		D_{10}	mm	0.046
		D_{50}	mm	0.129
		Ip	—	
III	Silt	FC	%	84.4
		D_{10}	mm	0.001
		D_{50}	mm	0.0137
		Ip	—	25.15
IV	Volcanic ash	FC	%	38.7
		D_{10}	mm	0.0042
		D_{50}	mm	0.1096
		Ip	—	-
V	Silt	FC	%	96.2
		D_{10}	mm	0.001
		D_{50}	mm	0.0049
		Ip	—	28.25
VI	Sandy gravel with Silt	FC	%	22.4
		D_{10}	mm	0.0078
		D_{50}	mm	1.4828
		Ip	—	8.35

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

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. In addition, the frozen undisturbed samples were taken in the layers at point A to perform the cyclic triaxial compressin test and to examin the posibility of lliquefaction. The sampligs were done in the following depths:

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

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

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

The liquefaction prediction methods were as follows:

1) Guidance of the Facilities Design of Fishing Port and Fishery (version 2003, Method A), 2) Simplified Prediction Method (SPM) of Specification for Highway Bridges(version 2003, Method B), 3)Momentary Deformation Modulus method (MDM, Method C).

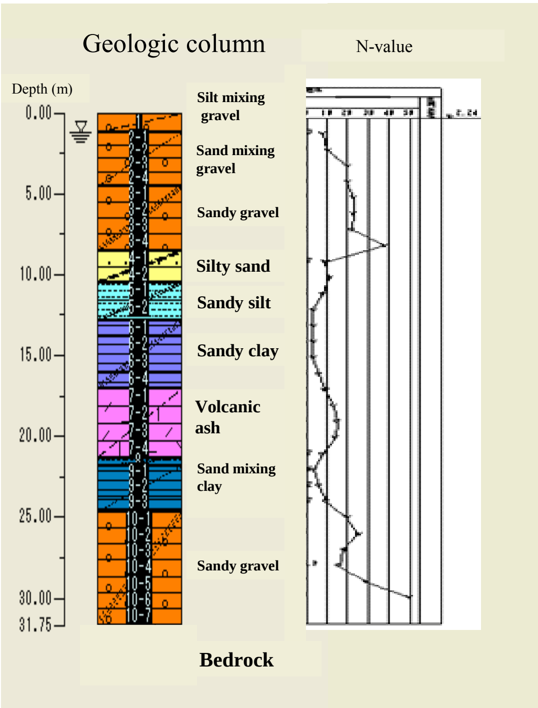

Fig.3 Boring log (Point A)

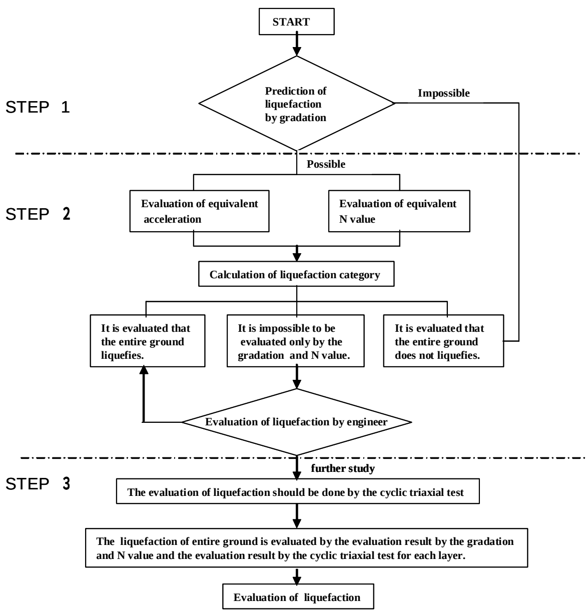

Fig.4 Evaluation flow of liquefaction

2.1 Guidance of Facility Design of Fishing Port and Fishery (Method A)

According to Guidance of Facility Design of Fishing Port and Fishery, the prediction flow of liquefaction is shown in Fig.4. The prediction is performed by the following three steps :

1) Evaluation by grain size

The liquefaction potential of each layer is evaluated by the uniformity coefficient and the coefficient of permeability. The borderline of the uniformity coefficient is 3.5.

2) Prediction and evaluation by equivalent acceleration and equivalent N value

The category of liquefactin potentaial Ⅰ - Ⅳ, as showun in table 2, is evaluated by the equivalent acceleration and equivalent N value of the each soil stratum.

The equivalent acceleration should be obtained by the seismic response analysis such as the equivalent linearization method. In this study, MDM method was used as described later. The evaluation result by Method A is shown in Fig.5, and the evaluation method is shown in Table 2.

Table 2 Category of liquefaction by gradation and N value

Category	Prediction of liquefaction by gradation and N value	Prediction of liquefaction by gradation and N value
I	Liquefies	It is estimated that the liquefaction occurs.
II	Strong possibility of liquefaction	It is estimated that the liquefaction occurs, or it must be predicted by the cyclic triaxial test.
III	Bare possibility of liquefaction	It is estimated that the liquefaction does not occurs, or it must be predicted by the cyclic triaxial test.
IV	No possibility	It is estimated that the liquefaction does not occur.

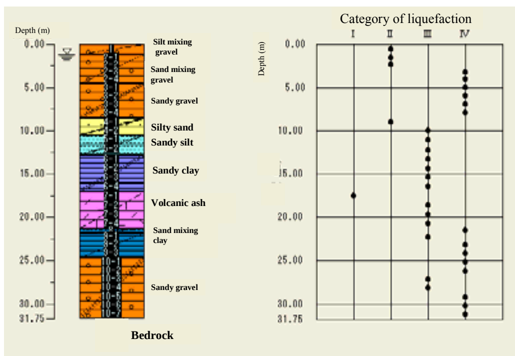

Fig.5 Liquefaction category at Point A

From the evaluation result of liquefaction as shown in Fig.5, the liquefaction categories are Ⅱand Ⅲin the middle soil layers at the depth of 8 －23 m. Since there is the possibility of liquefaction, the cyclic triaxial test was performed. The test results will be shown later.

3)Liquefaction evaluation by cyclic triaxial test

When the liquefaction evaluation was unable to evaluated by the liquefaction evaluation result 1),2)results, the cyclic triaxial test of the undisturbed sampling was executed. And the shearing stress during earthquake was compared with the liquefaction resistance of ground. One example of the result of cyclic triaxial test is shown in Fig.6 and 7. By the procedure of Method A, R = 0.36 was obtained from Fig.7. Since L is 0.26 by Step2, F_L value 1.39 was obtained.

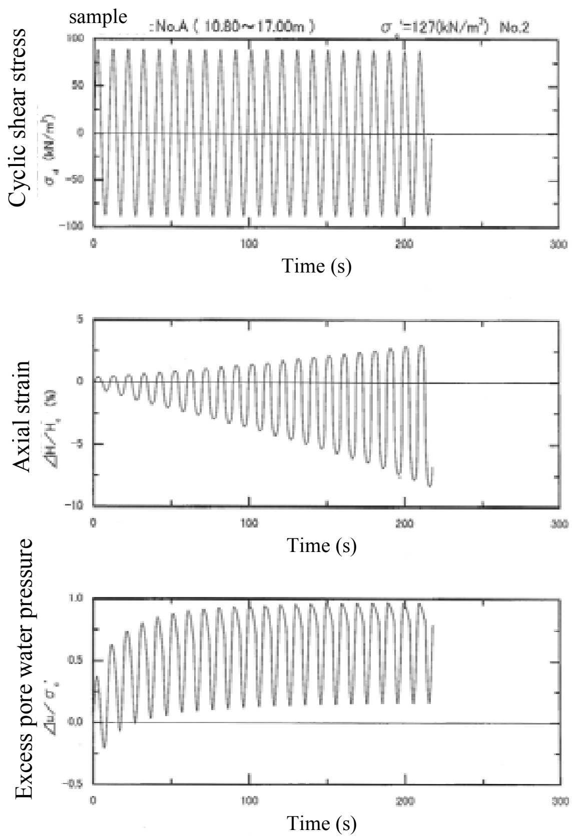

Fig.6 Example of the result of cyclic triaxial test

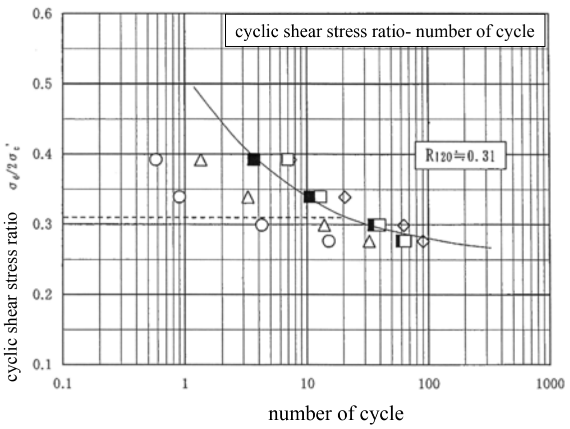

Fig.7 Test result of liquefaction strength

2.2 Simplified Prediction Method (Method B)

1) Evaluation of liquefaction

The rate of liquefaction resistance FL is calculated by Formula(1) on the assumption of Type Ⅱ earthquake motion to the soil layers, which need the evaluation of liquefaction. The soil layer, which F_L 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

R is obtained by the relation between equivalent N value and the cyclic triaxial test results of the sandy soil, which is corrected by the rate of fine-grained soil, the relation between equivalent N value and the cyclic triaxial strength tests of the gravelly soil, and the characteristics by the types of earthquake motion (Type Ⅰ and Type Ⅱ).

L is obtained by the Formula (2).

$$L = \gamma_d K_{hg} \sigma_V / \sigma_V' \qquad (2)$$

where:

γ_d : decrease coefficient in the direction of depth

k_{hg}: standard design seismic coefficient of Level 2 earthquake motion

σ_V: total overburden pressure

σ_V': effective overburden pressure

2) Liquefaction potential P_L

P_L value is obtained by Formula (3) from the underground water level to GL-20m in depth.

$$PL = \int_0^{20} (1 - F_{L,Z})(10 - 0.5z)dz \qquad (3)$$

where:

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

2.3 Momentary Deformation Modulus Method (Method C)

Neither the amplification nor the damping of the earthquake wave by the soil structure was considered in Method B. The liquefaction evaluation was made by using Method C from the view point of the accuracy for the liquefaction evaluation. The liquefaction of each stratum was evaluated by the rate of liquefaction resistance F_L, and the liquefaction potential in plane was evaluated by P_L value.

1) **Calculation of shearing stress ratio L during earthquake**

Fig.8 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 district based on "The second basic study of earthquake in Kochi Prefecture". The seismic response analysis was performed by the one-dimensional total stress seismic response analysis by using Method C. 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 Pubic Works Research Institute and Ports and Harbors Research Institute.

The energy dissipation was considered for the engineering bedrock which was half space ground and consecutive nonlinear analysis is performed in this analysis.

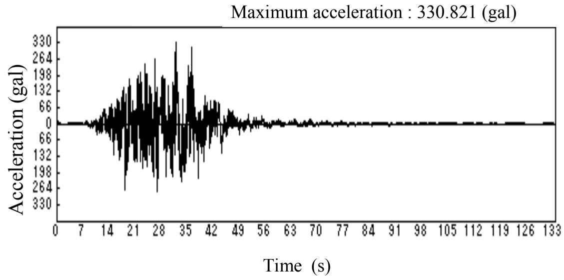

Fig.8 Input seismic wave

2) 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 and the conventional method for liquefaction strength (Method B)were used. The example of the liquefaction evaluation result by method C at point A is shown in Fig.9.

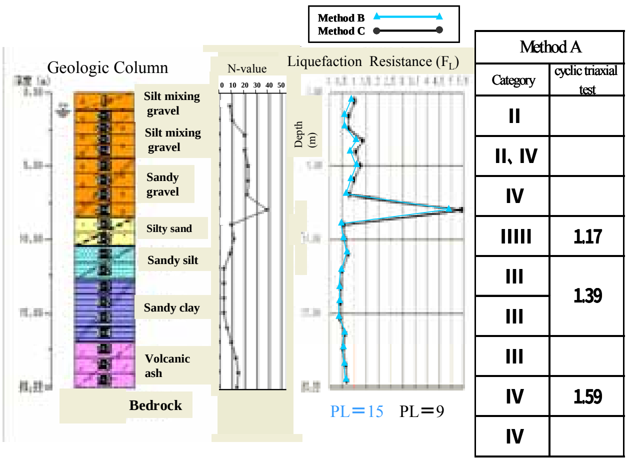

Fig.9 Comparison of liquefaction evaluation

3. DISCUSSION OF ANALYTICAL RESULTS

The example of the comparison on the liquefaction evaluation results by each method is shown in Fig.9.

Although the layers except gravel layers have the poor possibility of liquefaction (III), and evaluated not liquefaction from the cyclic triaxial test by Method A. Method B showes the occurrence of liquefaction whithout galavel layer and showes the conservative distribution of F_L value compered with Metod C (P_L=18 by Method C, PL=24 by Method B). In Method C, there is no meaningful difference between the case of using the cyclic triaxial test data and the case of no use of the cyclic triaxal test data. From these results, Method B was proposed as " Basic Guidelines of liquefaction Evaluation method in the fishing village " becase of the conservativenrss and the convenience to be applied for the liquefaction evaluation of coastal regions tentatively.

4. MAKING OF HAZARD MAP

The liquefaction hazard map in this area was made as shown in Fig.10 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.

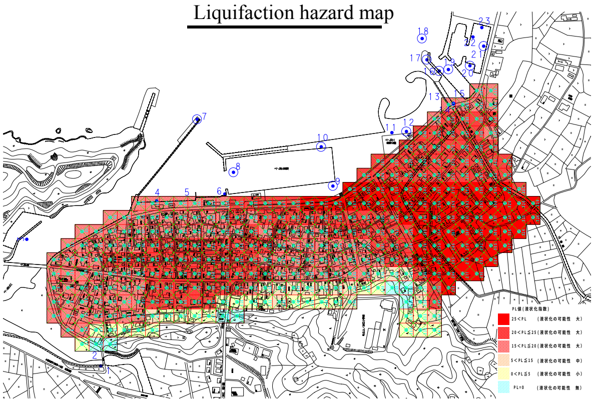

Fig.10 Liquefaction hazard map

5. CONCLUSION

The following conclusion were obtained as follows:

(1) The guidance of the facilities design of Fishing Village and Fishery gives the strong liquefaction potential.

(2) The simplified prediction method of Specification for Highway Bridges shows the same liquefaction tendency as the method of Momentary Deformation Modulus.

(3) The simplified prediction method of Specification for Highway Bridges is recommendable as the " Basic guideline of liquefaction evaluation method for Fishing Village and Fishery " .

And the future problems were clarified as follows:

1) It is necessary to confirm the reliability of the strong seismic motion to be input.

2) It is necessary to investigate the inference by the soil characteristics to analysis results.

3)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.

REFERENCES

Fishing Port Fishery Society, *Guidance of Facilities Design of Fishing Village and Fishery 2003.*

Japan Road Association, *Specifications for Highway bridges, Part V; Seismic Design 2002* .

Kumazaki,I. History model of soil and steel that considers the maximum strain level dependency of rigidity at minimum strain, *Civil Engineering association thesis collection,* No.743/III-64, pp.1-20, Septenber 2003.

Ministry of Construction Pubic Works Research Institute, Numerical analysis method of response characteristic at earthquake of the ground, *Ministry of Construction, Pubic Works Research Institute material,* No.1778,1982.

Ministry of Transport, Ports and Harbors Bureau, *Liquefaction measures handbook of innings* and pp.66-69,1997 .

Takenaka,K. and Okabayashi,K. Liquefaction prediction according to MDM method in Kochi prefecture for Nankai earthquake, *Civil Engineering association 59 annual science lecture meeting (in Japanese)*, 3-199 pp.119-120, 2004.