JSCE (Japan Society of Civil Engineers)
- NPO: EWB (Engineers Without Borders, Japan)
Joint Team
for
INSTRUCTIONS FOR GEOTECHNICAL INVESTIGATION AND THE PRACTICAL UTILIZATION OF ITS RESULTS FOR RECOVERY AND RECONSTRUCTION OF NIAS ISLAND AND FOR DISASTER PREVENTION OF NORTH SUMATRA AND WEST SUMATRA PROVINCE

Feb. 17 -25, 2007

Japan Society of Civil Engineers

Engineers Without Borders, Japan

in Collaboration with Civil Engineering Part of PII

(the Institution of Engineers, Indonesia (Persatuan Insinyur Indonesia).

1. PURPOSE OF DISPATCHING THE JSCE TEAM

A great earthquake with a magnitude of 8.5 hit North Sumatra, Nias Island on March 28, 2005. The earthquake caused extensive damage to mainly bridges, port facilities, houses and other buildings. Temporary repairs and Rehabilitation of infrastructures, load, bridges and so on is on of the most urgent subjects in Indonesia. By the request of a state legislature, JSCE dispatched the expert team to support the repair works and rehabilitation of public facilities in April 2005. The team visited Nias Island to investigate the damage to the infrastructure, and to make recommendations for temporary repair and rehabilitation to concerned government agency.

Especially, in Gunung Sitoli, the capital of Nias Island, its infrastructure including lifeline systems, which was seriously destroyed due to liquefaction of the ground, had no prospect of being re-constructed after many months elapsed from the earthquake. In order to initiate recovery and reconstruction work in the region, the soil exploration data such as boring data is essential. However, available data is scarce and not sufficient for recovery and reconstruction works at the present time. Therefore, Japan Society of Civil Engineers dispatched experts and engineers to Nias Island again and provided the expertise advises and technical supports for recovery and re-construction with the close cooperation of the Institution of Engineers, Indonesia (Persatuan Insinyur Indonesia: PII). In this project, Swedish Weight Sounding Test as an practical ground surveying methods was introduced to local engineers for the prediction methods of ground liquefaction and their applications to the recovery and reconstruction of the damaged areas.

Continuous training is necessary for the soil investigation method to be established in this region. Moreover, West Sumatra Province requested us to carry out the technical support and training local engineers for geotechnical investigations for earthquake disaster prevention. Therefore JSCE decided to dispatch the third Team of experts and engineers to Nias Island for providing the expertise advises and technical support for recovery and re-construction again, and also to Medan and Padang for providing the expertise advises and technical supports for earthquake disaster mitigation.

2. Roles of JSCE Team

The roles of The JSCE Team are as follows;

1) Continuation of the technical support and dissemination activity of transferred techniques, which have been done so far, for the reconstruction and future earthquake disaster mitigation activities in Sumatra island, and to implement those activities into the practical use.

a) Transferring the techniques on geotechnical investigations

・Training on ground survey methods with Swedish Weight Sounding Test

・Training on the assessment methods of ground liquefaction and counter-measures against ground liquefaction based on the data obtained from the ground surveys

・Training for applications of the obtained soil data to actual recovery and reconstruction projects

b) Assistance for preparing a hazard map, restoration plan of lifeline systems, urban planning, etc.

List of members

Name of the Project:

Instructions for geotechnical investigations in Nias Island for recovery and reconstruction and in Medan and Padang for Disaster prevention of North Sumatra and West Sumatra Province

(Japan Society of Civil Engineers and Engineers Without Borders, Japan)

Duration of Project: February 17-25, 2007.

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JSCE (Japan Society of Civil Engineers)- NPO: EWB (Engineers Without Borders, Japan) Joint TEAM FOR INSTRUCTIONS FOR GEOTECHNICAL INVESTIGATION AND THE PRACTICAL UTILIZATION OF ITS RESULTS FOR RECOVERY AND RECONSTRUCTION OF NIAS ISLAND AND FOR DISASTER MITIGATION OF NORTH SUMATRA AND WEST SUMATRA PROVINCE

Itinerary: February 17-25, 2007

[As of Feb. 10]

Date		Itinerary	Stay
Feb.17(Sat.)	1) 2) 3)	Leave for Indonesia JL 725: Departure from Narita at 11:20/ Arrival at Jakarta at 17:20 19:40 – 21:50: JAKARTA – MEDAN (GA 196) Internal Meeting	Medan Polonia
18(Sun.)	1) 2) 3)	9:00-15:00 Field Investigation in Medan with North Sumatra Road & Bridge office 16:00 Internal Meeting 17:00 - Preparation for the activity	Medan Polonia
19 (Mon.)	1) 2) 3) 4)	08:30 - 10:00: Meeting with Head of North Sumatra Road & Bridge Office 10:30 - 12:00: Courtesy call to Governor of North Sumatra 13:00 - 16:00: Training for engineers on Ground Survey Method in Medan 16:30 - 18:30: Lecture class for engineers in North Sumatra Province in Medan	Medan Polonia
20 (Tue.)	1) 2) 3) 4)	07:30 - 08:40: MEDAN - NIAS (MZ 5424) 10:00 - 12:00: Meeting with Regency Head, Meeting with Regency Head, Head of Regional Development Planning Board, Head of BRR of Nias Regency etc. 13:00 - 17:00: Training for engineers on Ground Survey Method in Gunung Sitoli city 18:00 - 20:00: Lecture class for engineers in Nias Island at Public Works Auditorium, Nias Regency	Nias Gunung Sitoli Mega Beach
21 (Wed.)	1) 2) 3) 4) 5)	09:00 - 12:00: Training for engineers on Ground Survey Method in Gunung Sitoli city 13:00 - 14:00: Meeting with Regency Head 15:25 - 16:35: NIAS - MEDAN (MZ 5427) 17:30: Meeting with Deputy Head of Road & Bridges Office, North Sumatra Province 19:30 Meeting with Japan Consulate General	Medan Polonia
22 (Thu.)	1) 2) 3) 4) 5)	07:00 - 08:00: MEDAN – PADANG (RI 089) 09:00 - 10:30: Meeting with West Sumatra Head of Road & Bridge Office 10:30 - 12:00: Courtesy call to Governor of West Sumatra 13:00 - 16:00: Training for engineers in West Sumatra Province on Ground Survey Method in Padang 16:30 - 18:30: Lecture class for engineers in West Sumatra Province	Padang Bumi Minang
23 (Fri.)	1) 2) 3) 4)	09:00 - 12:00: Training for engineers in West Sumatra Province on Ground Survey Method in Padang 13:00 - 15:00: Lecture class for engineers in West Sumatra Province 15:00 - 16:00: Meeting with West Sumatra Head of Road & Bridge Office 20:05 - 21:45: PADANG – JAKARTA (GA165)	Jakarta Nikko
24 (Sat.)	1) 2) 3) 4)	09:00 Meeting with PII 11:00 Meeting with JICA, JICS, JBIC (if possible) 15:00 Reports preparation 22:10 - 07:25 JAKARTA – NARITA(JL726)	
25 (Sun.)	1)	07:25 Arrival at Narita	

SUPPORT ACTIVITIES FOR THE RECOVERY AND RECONSTRUCTION BY TRANSFERING THE TECHNIQUE ON GEOTECHNICAL INVESTIGATION IN NIAS ISLAND DAMAGED BY THE M8.7 OFF-SHORE SUMATRA EARTHQUAKE, MARCH 28, 2005

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Ichiro ENDO[5], Tomoji SUZUKI[6] and Masanori HAMADA[7]

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Key Words: Reconstruction, Geotechnical Investigation, Swedish weight Sounding, Strong Motion, Liquefaction, Lateral Flow,

INTRODUCTION

The Sumatra Earthquake of December 26, 2004 caused the most disastrous tsunami in Indian Ocean and great disaster to the countries around the Indian Ocean, especially in Indonesia. Three months after the earthquake, another large earthquake with a magnitude 8.7 occurred on March 28, 2005 nearby Nias Island at the west coast area of Sumatra 500km away from the epicenter of the 2004 earthquake. Severe damage was caused by strong ground motion especially in Nias Island. For these disasters, Japanese organizations in cooperation with some Indonesian organizations conducted support activities for the recovery and reconstruction of the affected areas. These included making recommendations and giving instructions for geotechnical investigations and the practical utilization of its results for temporary repair and rehabilitation of infrastructures and buildings (e.g. Support Team of JSCE, 2005; Miwa et al., 2006a). Also educational activities on disaster prevention (e.g. Hamada et al., 2005a; Tsukazawa et al., 2005; Kitajima et al., 2006) as well as the reconnaissance surveys of earthquake affected areas. In this article, the support activities for recovery and reconstruction on transferring a geotechnical investigation and example of its result conducted by JSCE team (e.g. Aydan et al. 2005; Miwa et al. 2006a, Miwa et al. 2006b, Miwa et al. 2007).

SUPPORT ACTIVITIES FOR RECOVERY AND RECONSTRUCTION

Background of activities

After the Sumatra Earthquake of December 26, 2004, which caused the most disastrous tsunami in Indian ocean and severe disaster to the countries around the Indian Ocean, especially in Indonesia, Japan Society of Civil Engineers (JSCE) had dispatched a reconnaissance team to Banda Ache for the investigation of the damage to Infrastructures such as road, bridges, port facilities, riverbanks and lifeline systems in February, 2005 (Goto et al., 2005). Also, JSCE dispatched an expert team for disaster prevention education to assist the educational activities for young people on tsunami and earthquake disaster in cooperation with the government agencies of the concerned countries. In order to continue and enlarge such an activity, students of Waseda and Kyoto University have conducted disaster prevention education several times at damaged and liable to damage areas in Indonesia, in 2005 and 2006.

On the other hand, temporary repairs and rehabilitation of infrastructures, like roads, bridges and so on are of the most urgent subjects in Nias Island since many structures were damaged by strong ground motion during the large earthquake that occurred on March 28, 2005. By the request of government and legislature of province, JSCE dispatched the expert team to support the repair works and rehabilitation of public facilities in April 2005. The team visited Nias Island to investigate the damage of the infrastructure, and make recommendations for temporary repair and rehabilitation to concerned government agencies such as the Nias public work office and the government of the province of North Sumatra.

For example, the contents of the recommendations are as follows. As for the bridges, temporary supporting methods were introduced for the emergency stage. The existing truss decks of bridges can be used with some replacement of damaged parts for economical reconstruction during the reconstruction stage, but almost all bridges should be re-constructed because foundation structures were heavily damaged due to ground failure such as lateral movement or liquefaction. Pile design should be re-considered and their length should be sufficiently long to have required end bearing. The foundation pile should be designed to resist to the lateral flow force of liquefied ground. As for the foundation of buildings, box-like (mat, raft) foundations should be used in liquefiable areas in case piles could not be used. As for the structural design of foundation structures and for urban rehabilitation planning, ground investigations should be done to have fundamental data on ground characteristics.

Transferring the technique on geotechnical investigations

Although nine months elapsed from the earthquake at the end of 2005, the infrastructures and buildings in Nias Island had still no prospect of being re-constructed. In order to initiate recovery and reconstruction work in the region, the soil exploration data such as boring data is essential. However, available data is scarce and not sufficient for recovery and reconstruction works at the present time. Also, government of the province of North Sumatra requested for continuation of support. Therefore, experts and engineers were dispatched again by JSCE to Nias Island and the expertise advises and technical supports for recovery and re-construction were provided as the joint activity with the Institution of Engineers, Indonesia (Persatuan Insinyur Indonesia: PII) in January 2006.

In this project, transferring the technique on geotechnical investigations was one of the major purposes. Swedish Weight Sounding Test as an practical ground surveying methods was introduced to local engineers for the prediction methods of ground liquefaction and their applications to the recovery and reconstruction of the damaged areas. JSCE donated one Swedish cone penetration device to the Public works office of Nias Island Local Government upon the training of engineers. Also, JSCE donated the second device with an additional pull out device to Road and Bridge Office, North Sumatra Province October 2006. Activities of the support team were as follows; 1) Training on ground survey methods with Swedish Weight Sounding Test, 2) Training on the assessment methods of ground liquefaction and counter-measures against ground liquefaction based on the data obtained from the ground surveys, 3) Training for applications of the obtained soil data to actual recovery and reconstruction projects.

Swedish weight sounding tests were conducted by engineers in Indonesia under the instruction of engineers from Japan at two locations in Gunung Sitoli and at one location at Idano Gawo bridge in Nias Island, not only for obtaining the geotechnical information but also for training the local engineers at the technique on geotechnical investigations. Also, short courses for engineers in Nias Island and North Sumatra province were held on the utilization of the data obtained from the ground survey for the bearing capacity, the liquefaction assessment and so on. Meetings with the government of Nias prefecture, Agency of Recovery for Banda Aceh and Nias, North Sumatra road and bridge office were held about the activities at that time and in the next period of time. Figure 1 shows a photo of training of Swedish Weight Sounding Test. Training was continued until night. Figure 2 shows the photo of the short course in Nias Island and the meeting with the Governor of North Sumatra Province.

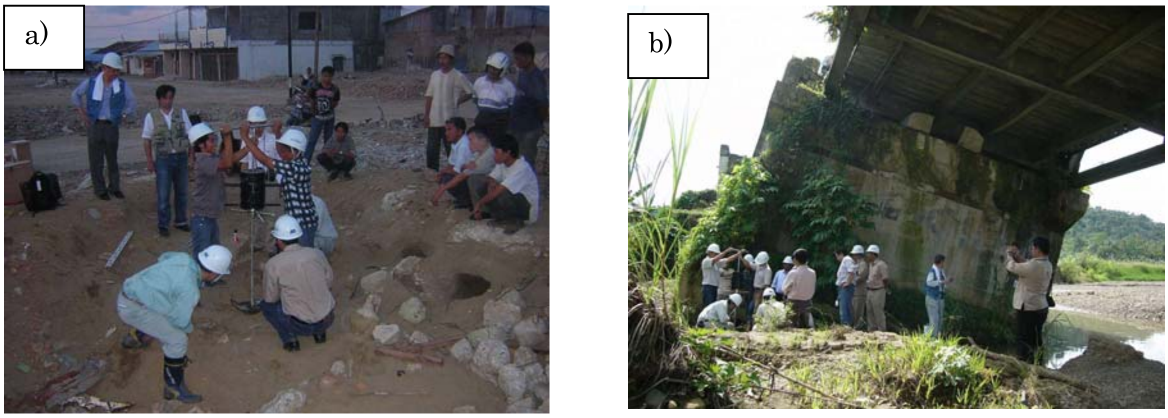

Figure 1. Training on Swedish Weight Sounding Test at (a) Gunung Sitoli b) Idano Gawo Br.)

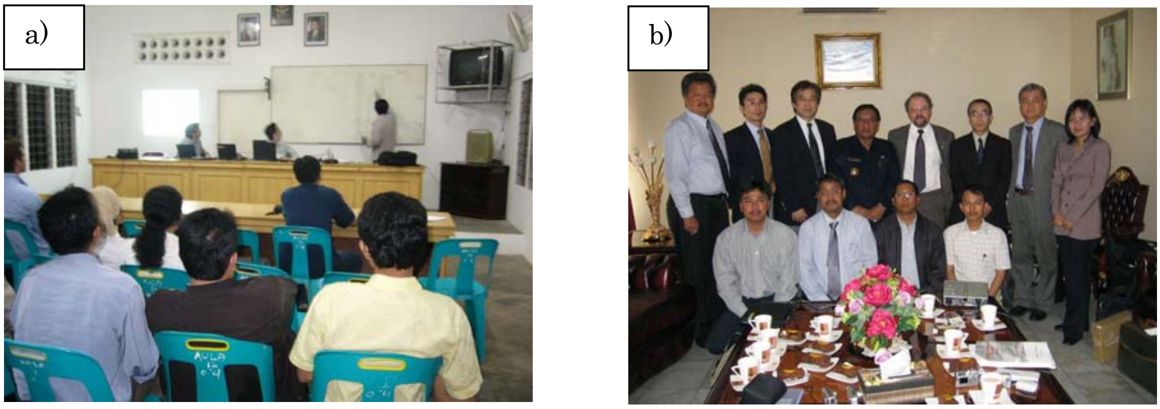

Figure 2. a) Short course in Nias Island, b) Meeting of the Government of North Sumatra Province

Issues for the future

In the future, the direct contribution of civil engineers to the society will be one of the most important issues. The activity at this time, which is an example of the direct contribution to the society, made a positive influence in training of engineers on geotechnical investigation and the planning of recovery and reconstruction projects to be carried out in Nias Island and other disaster-affected regions. However, the geotechnical investigations of ground are still lacking in Nias Island and it would be desirable to carry out both such technical support activities and investigations by local engineers in Nias Island. Continuation of the technical support and dissemination of transferred techniques, which have been done so far, are necessary for firm establishment of the technique for the reconstruction and future earthquake disaster prevention activities in Sumatra island, and implement those activities to the practical use. In order to continue the support activities for recovery and reconstruction of affected region or country, raising funds and recruiting talented people are necessary. Therefore, it is important to establish collaborative relationships among the societies of engineers, universities, government, local governments, citizens, citizens' group and private enterprises in Japan. NPO is thought to be most suitable and make such activities easier as compared with existing organizations. Therefore, NPO “Engineers without Borders, Japan” has been established for such a purpose (Hamada, 2005b).

As for the actual activity in the country suffered by disaster, it is important to make collaborative relationships with the society of engineers, universities, local governments and private enterprises in the countries affected by the disaster. At present time, a member of PII and some members of soil investigation companies and construction companies participated in our activity and took part of the work like translation the English materials to Indonesian, explanation in Indonesian language to the local engineers, logistics and so on. As for transferring the technique for soil investigation, in order to be used continuously in the region, machines should be simple and the prototype of a machine should be donated so that the required quantity of machines can be manufactured in the region.

Continuous training is necessary for the soil investigation method to be taken root in this region. Moreover, West Sumatra Province requested us to carry out the technical support and training local engineers for geotechnical investigations for earthquake disaster prevention. Therefore, JSCE decided to dispatch a third Team consisting of experts and engineers to Nias Island for providing the expertise advises and technical supports for recovery and re-construction again, and also to Medan and Padang for providing the expertise advises and technical supports for earthquake disaster mitigation between February 17 and February 25, 2007, next week. The roles of The JSCE Team are as follows;

1) Continuation of the technical support and dissemination activity of transferred techniques, which have been applied so far, for the reconstruction and future earthquake disaster mitigation activities in Sumatra island.

a) Transferring the techniques on geotechnical investigations

・Training on ground survey methods with Swedish Weight Sounding Test.

・Training on the assessment methods of ground liquefaction and counter-measures against ground liquefaction based on the data obtained from the ground surveys.

・Training for applications of the obtained soil data to actual recovery and reconstruction projects.

b) Assistance for preparing a hazard map, restoration plan of lifeline systems, urban planning, etc.

SWEDISH WEIGHT SOUNDING TEST

Swedish Weight Sounging Test is one of the sounding test used for measuring the static penetration resistance of soft ground in 10m. SPT-N Value, Bearing capacity, unconfined compressive strength can be obtained from the result of the test by using the relationship of the result of the test and strengh, bearing capacity of the soil. İt is useful for obtaining the basic characteristics of soil at the damaged area for reconstruction. Figure 3 shows the flowchart of Swedish Weight Sounding Test. Figure 4 shows the equipment of the Swedish Weight Sounding Test. Figure 5 depicts the relationship between N-value and Wsw, Nsw, which are the results obtained from the test. Once SPT-N value is obtained, liquefaction assesment can be conducted, that is very useful for reconstruction at the liquefieable area.

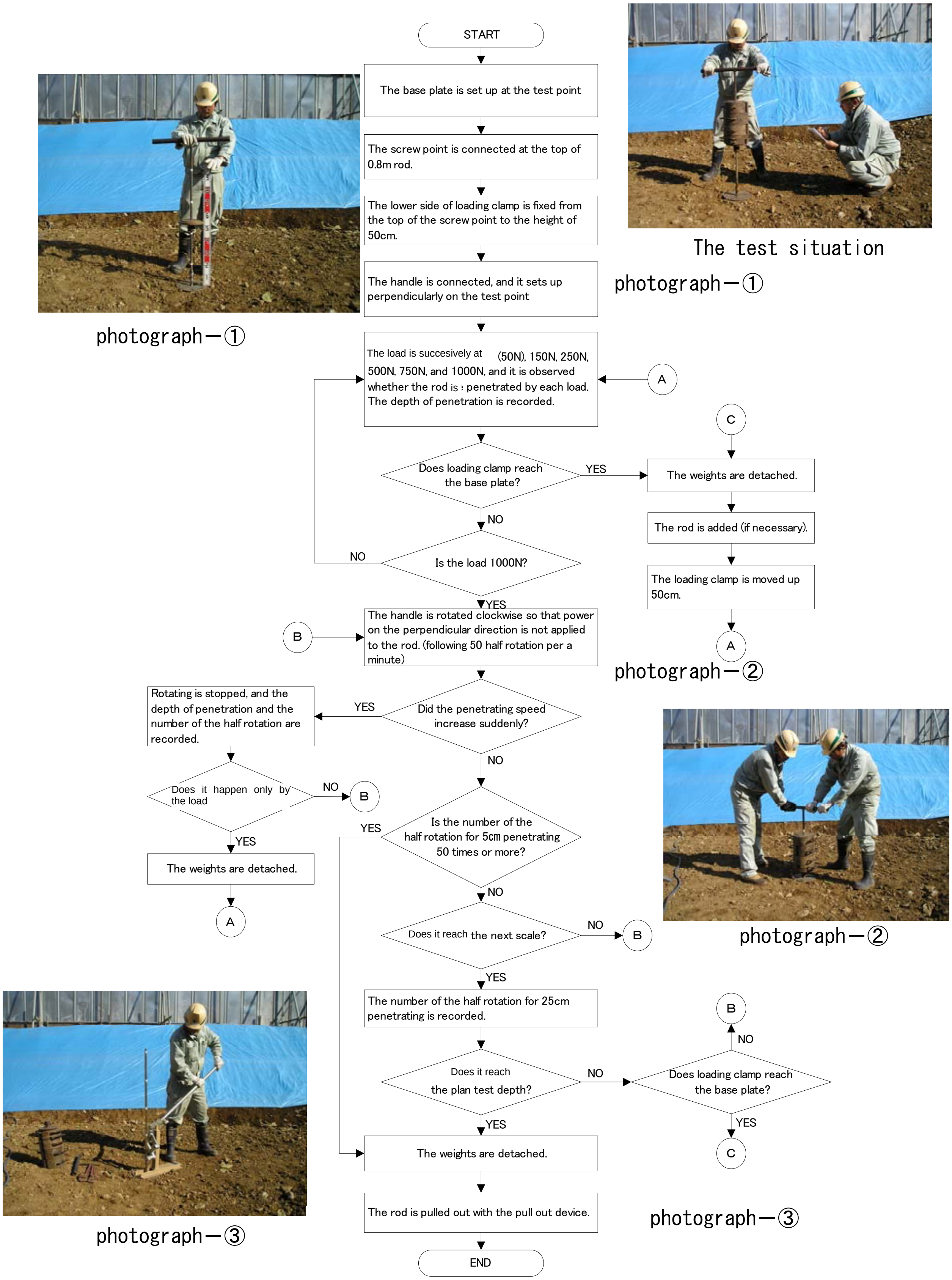

Figure 3. Flowchart fo the Swedish Weight Sounding Test

Figure 4. Equipment of the Swedish Weight Sounding Test

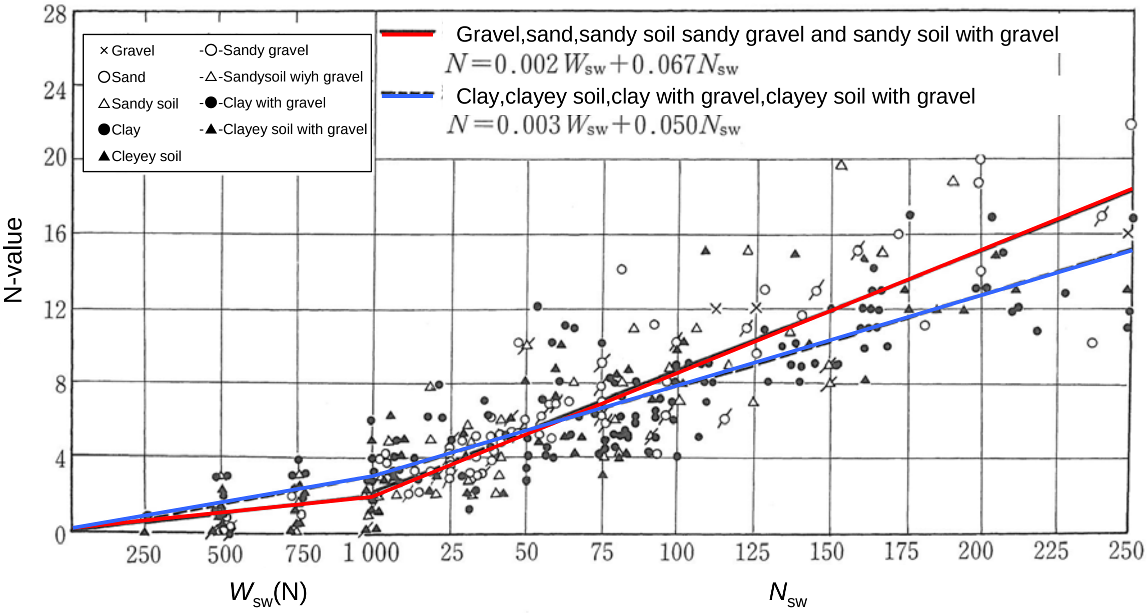

Figure 5. Relationship between N-value and Wsw, Nsw, (JGS, 2004)

APPLICATION OF GEOTECHNICAL INVESTIGATION FOR LIQUEFIED AREA

As expected from the magnitude of this earthquake, the liquefaction of sandy ground is very likely. The sandy ground is observed along seashore and riverbanks in Nias Island. Permanent ground movements such as settlement and lateral spreading, and associated structural damage due to liquefaction were widely observed in various locations along the coastal area and reclaimed ground. The lateral spreading of ground nearby bridge abutments were almost entirely associated with liquefaction of sandy soil layer. The damage induced in Gunung Sitoli due to ground liquefaction is widespread along the coastal area, reclaimed ground and riverbanks. All the possible forms of ground movements and the effects of ground liquefaction were observed such as sand boils, lateral ground movements and settlement. As a result, many buildings in such areas were heavily damaged with partial settlement, inclination and uplift of ground floor. The buildings without raft foundations and continuous tie-beams could not resist to ground failures due to liquefaction unless they are built on piles extending into the non-liquefiable layer. Figure 7 shows the damages of buildings due to liquefaction. In Figure 8 grain size distribution curves for soil samples in Gunung Sitoli can be seen. It can be seen that these soils have almost the same grain size and they are very liquefiable. Swedish weight sounding tests were conducted at 2 points in Gunung Sitoli. Soil profile, converted SPT N-value from Swedish weight sounding test and Liquefaction Potential based on the result of geotechnical investigation are shown in Figure 9.

Figure 6. Effect of liquefaction and lateral spreading on RC building and truss bridge

Method of liquefaction assessment is according to the Recommendation for Design of Building Foundations, Architectural Institute of Japan (Architectural Institute of Japan, 2001). In this study, maximum acceleration of strong ground motion is taken as 350cm/s^2 for ultimate limit, which is as large as observed in liquefied area during the Hyogoken-Nambu earthquake. There is a 3m thick loose sandy layer at the subsurface of reclaimed ground (see the case of shop house in Figure 8), which is inferred to be easily liquefiable from the result of Swedish weight sounding. As mentioned above, many buildings in such areas were heavily damaged with partial settlement, inclination and uplift of ground floor. As a result, almost all buildings were demolished. At the site of Governor's house, there exists a sandy layer, but having relatively large N-value and partially liquefiable during strong ground motion obtained from the assessment based on the test result. The elevation of the site is slightly higher than that of the reclaimed area and only small damages such as cracking in floor concrete were observed after the earthquake.

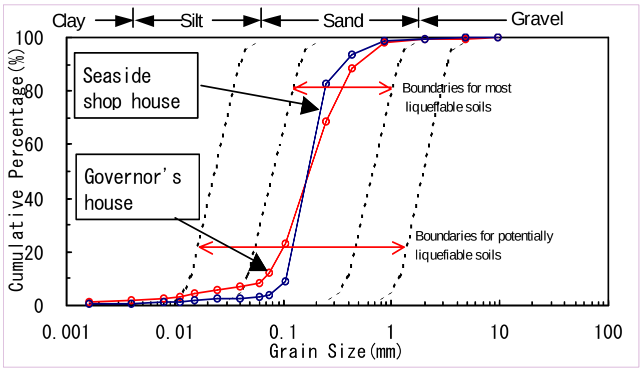

Figure 7. Grain size distribution curves for soils at 2 sites in Gunung Sitoli

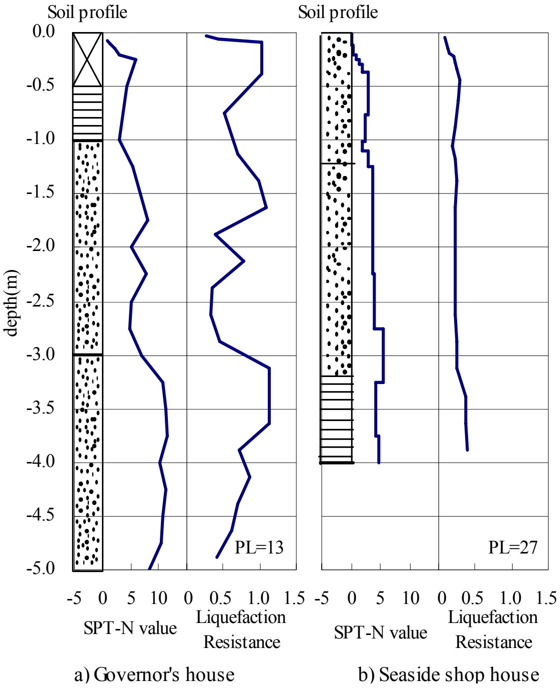

Figure 8. Soil profile, Converted SPT N-value from Swedish weight sounding test and liquefaction resistance at 2 sites in Gunung Sitoli

The results obtained from geotechnical investigation are in accordance with the observed damages caused by the earthquake. However, the geotechnical investigations of ground are scarce in Nias Island and it would be desirable to carry out such investigations in areas particularly affected by ground liquefaction in relation to recovery and reconstruction of Nias Island.

CONCLUSIONS

The conclusions obtained from the investigations and support activities in Nias Island following the March 28, 2005 earthquake are summarized as follows:

1) A very large earthquake with a magnitude of 8.7 occurred nearby Nias Island of Indonesia on March 28, 2005. Strong ground motions induced large number of casualties and damaged infrastructures such as roads and bridges, and buildings.

2) The team of experts was dispatched and made recommendations for temporary repair and rehabilitation of infrastructures and buildings. Because available soil investigation data is scarce and not sufficient at the present time, the Swedish Weight Sounding Test as a practical ground surveying method was introduced to local engineers for the prediction methods of ground liquefaction and their applications to the recovery and reconstruction of the damaged areas.

3) Support activities for recovery and reconstruction as well as disaster prevention education or technical support to the area suffered by natural disaster should be conducted and continued as the direct contribution of the society of civil engineers. In order to continue the support activities for recovery and reconstruction, the building of good collaborative relationships between the government, local governments, societies of engineers and NPO both in Japan and the country affected by the disaster are necessary.

ACKNOWLEDGEMENTS

The activities described in this paper are mainly the activities of the Support Team of the Japan Society of Civil Engineers (JSCE) for the Restoration and Rehabilitation of Infrastructures and Buildings and the Joint Team of JSCE and Institution of Engineers, Indonesia (PII) for Instruction for Geotechnical Investigation and the Practical Utilization of its Results for Recovery and Reconstruction of Nias Island. The Infrastructure Development Institute – Japan, supports a Part of this activity. The contribution and the support for this work are highly appreciated. The authors would also like to thank all members of many organizations in Indonesia and Japan for the cooperation and support to prepare the material, to conduct investigation, to hold meetings, to provide training courses in Nias Island, Medan and Jakarta. We are also very thankful to local people for their cooperation, although they suffered most from the earthquake consequences. Finally, we are honored and proud to be the first team of Engineers Without Borders, Japan to disaster area.

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Miwa, S., Aydan, Ö, Kodama, H., Kiyono, J., Endo, I., Suzuki, T. and Hamada, M.: “Damage in Nias Island Caused by the M8.7 Off-shore Sumatra Earthquake, March 28,2005 and The Support Activities for the Recovery and Reconstruction, Proc. of 4th International Conference on Earthquake Geotechnical Engineering, (Submitted), 2007.

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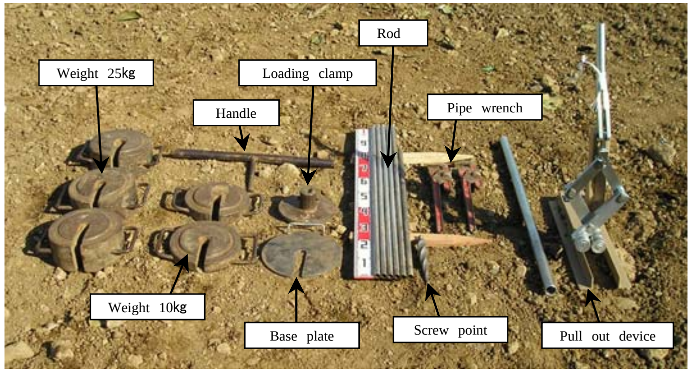
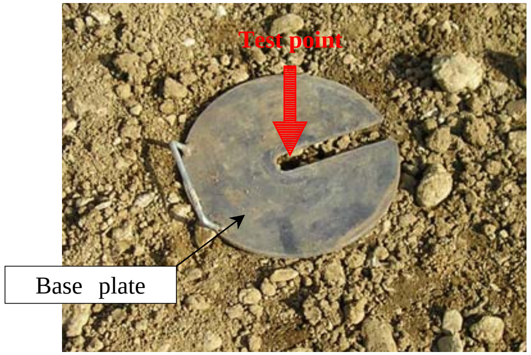
Swedish weight sounding test

Sounding equipment



The base plate is set up in the test point.

The center of the base plate is matched to the test point.



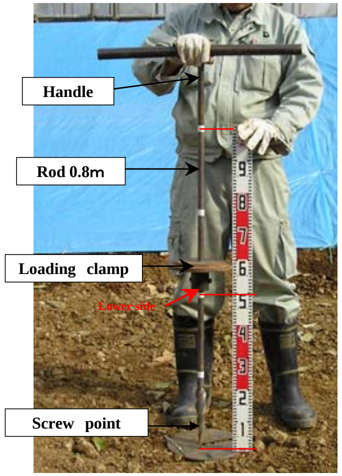
The screw point is connected at the 0.8m-rod.

↓

The lower side of loading clamp is fixed from the top of the screw point to the position of 50cm.

↓

The handle is connected, and sets up perpendicularly on the test point.



The load is successively at (50N), 150N, 250N, 500N, 750N, and 1000N, and it is observed whether the rod be penetrated to the ground by each loading step.
The penetrating depth is recorded when would penetrate.


150N（15kgf）


500N（50kgf）


1000N（100kgf）

※1kgf≒10N

CAUTION！

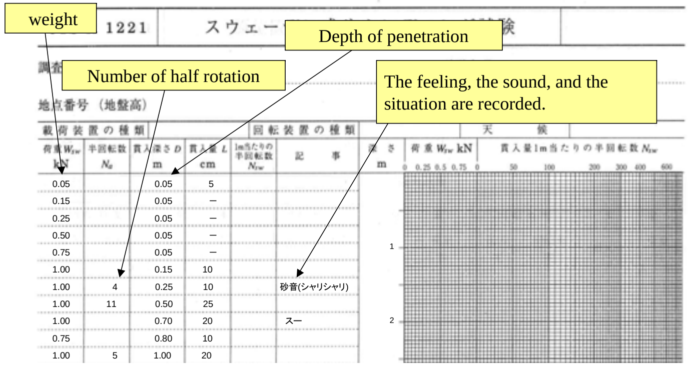
If the weights is put from the same direction, the weights fall when the rod inclines

The handle is rotated clockwise so that power in a perpendicular direction is not applied to the rod.

Rotational speed＝Following 50 half rotation per a minute
＝a rotation 2.4sec or more

Because the screw point comes off, it is not rotated by the turn.

The number of the half rotation that requires it for 25cm penetration is recorded.


weight

Depth of penetration

Number of half rotation

The feeling, the sound, and the situation are recorded.

1221　スウェー

地点番号（地盤高）

載荷装置の種類　回転装置の種類　天候

荷重 W_{sw} kN	半回転数 N_a	貫入深さ D m	貫入量 L cm	1m当たりの半回転数 N_{sw}	記事
0.05		0.05	5		
0.15		0.05	—		
0.25		0.05	—		
0.50		0.05	—		
0.75		0.05	—		
1.00		0.15	10		
1.00	4	0.25	10		砂音(シャリシャリ)
1.00	11	0.50	25		
1.00		0.70	20		スー
0.75		0.80	10		
1.00	5	1.00	20		

When loading clamp reaches the base plate, weights is unloaded, and loading clamp is moved up 50cm.

↓

The load is increased up to 1000N, and rotating penetration is repeated.

Method for moving up loading clamp

The handle is detached from the rod with two pipe wrenches.

The rod of 1.0m in length is added.

The handle is connected to the additional rod.

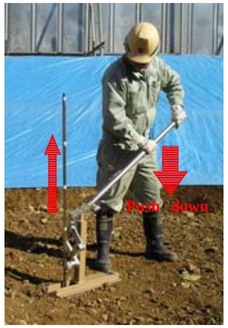
Loading clamp is moved up 50cm.

Judgment of test end

1. When the depth of penetration reaches the depth of the schedule.
2. When the number of the half rotation for 5cm penetration is 50 times or more.
3. When the repulsion power of the handle is very large, and the rotation is difficult.
4. When running idle on the stone etc.

When an enough test result is not obtained, a test done again in the point near about 50cm.

Loading Clamp, handle, and weights is detached from the rod, and the rod is pulled out with the pull out device.



Pull out device

Method of the test

a. Before the test, damage inspection of the screw point, loading device and rotating device should be conducted.

b. Screw point is connected at the top of the rod for connecting to the screw point, adding device is fixed on the rod, and test device is set on the exploration point, vertically and supported.
If there is the possibility that the loading device is submerged at the start of the test, subsidence should be prevented by setting the base plate and so on.

c. Weight of the 50N is loaded at first.

d. The situation of the penetration is observed. In the case that penetration advanced only by the load, the length of penetration at the load after stopping of the penetration is measured.

e. The process of d) is repeated by increasing the load. Loading steps are 50N, 150N, 250N, 500N, 750N and 1000N. According to the purpose of the test, load steps can be 500N, 750N and 1000N.

f. When the bottom of the loading device reaches at the surface of the ground, Load (Weights) is removed, rod is added and loading device is moved up to appropriate height and fixed. The processes between c) and e) are repeated.

g. If the penetration of the rod with the load 1000N stopped, the length of penetration is measured, after that, the rod is rotated in clockwise without additional vertical force, the number of half rotation of the rod penetrating to the next scale is measured. The speed of rotation should be less than 50 half rotations per minute. After this, the measurement is conducted the every 25cm scale.

h. In the case that penetration speed increases rapidly during the rotation of the rod, rotation is stopped and the test only by load of 1000N is conducted to confirm that penetration advance or stop. In the case that the penetration advances, the process d) and continuing process is conducted. In the case that the penetration stops, the process g) and continuing process is conducted.

i. In the case that penetration speed decreases rapidly during the rotation of the rod, the length of penetration and the number of half rotation at the time is measured, and the penetration is continued.

j. When screw point reaches the hard layer where the number of half rotation per 5cm penetration is more than 50, the reaction force is remarkably large at the rotation of the rod, or the rod hits a large stone and runs idle on that, measurement can be over.

k. After the measurement, the loading device is removed, the rods is removed by the pulling out device. number of the rod is checked, and the damage of the screw point is checked

Record and arranging

a. In the case that penetration advanced only by the load, the weight of the load W_{sw}, the depth of the top of the screw point from the surface of the ground D is recorded, also the length of penetration at the load L is recorded.

b. In the case that penetration advanced by rotation with the load of 1000N, the number of the half rotation and the corresponding depth of the top of the screw point from the surface of the ground D is recorded, and the length of penetration at the load L is calculated.

c. The number of half rotation corresponding to the length of penetration L is converted to the numbers of half rotation per the 1m penetration N_{sw}, by using the equation as follows,

$$N_{sw} = 100N_a/L$$

N_{sw} is rounded to an integer that is nearest to the original number.

If L=25cm, N_{sw} =4 N_a

Where

N_{sw}: the numbers of half rotation per the 1m penetration (times/m)

N_a: The number of half rotation (times)

L: the length of penetration (cm)

Report

a. Point No.
b. Height at the test point.
c. Date of the test.
d. Name of member who conducted the test.
e. Kind of the loading device and rotating device.
f. Measurement records, calculated table and situation of the test.
g. Figure for the distribution of the Static penetration resistance W_{sw} and N_{sw} in depth.

Interpretation and utilization of the test results

a. Relation with the N-value

Gravel, Sand, Sandy soil

$$N = 0.002W_{sw} + 0.067N_{sw}$$

Clay, Clayey soil

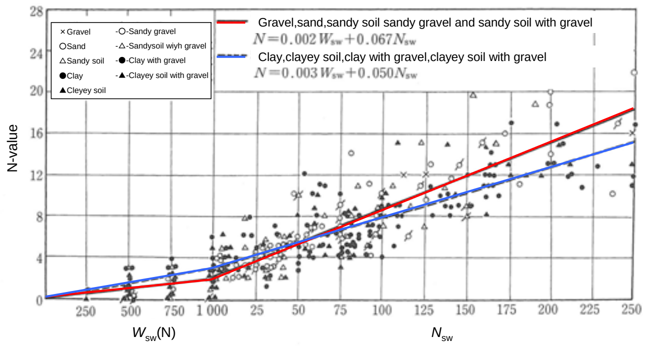
$$N = 0.003W_{sw} + 0.050N_{sw}$$

where

W_{sw} : the load in the case of penetration only by the load below 1000N（N）

N_{sw} : the numbers of half rotation per the 1m penetration after the penetration by the load of 1000N stopping（回/m）

Relationship between N-value to W_{sw}, N_{sw}



b. Relation with the unconfined compressive strength

$$q_u = 0.045 W_{sw} + 0.75 N_{sw}$$

where

q_u : unconfined compressive strength (kN/m^2)

W_{sw} : the load in the case of penetration only by the load below 1000N (N)

N_{sw} : the numbers of half rotation per the 1m penetration after the penetration by the load of 1000N stopping

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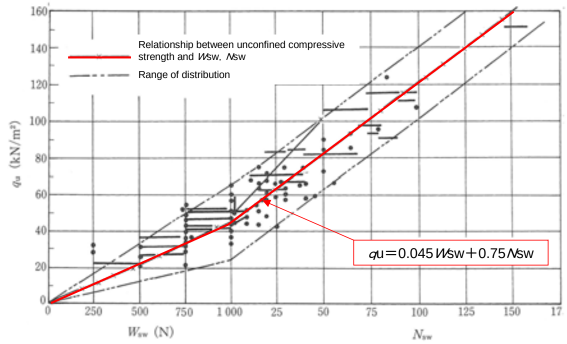
Relationship between unconfined compressive strength and W_{sw}, N_{sw}



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c. Relation with the bearing capacity

(a) relation with the bearing capacity buy the plate bearing test

$$W_{sw} \leqq 1000\text{N} \cdots\cdots q_a = 0.00003(W_{sw})^2$$
$$W_{sw} = 1000\text{N} \cdots\cdots q_a = 30 + 0.8 \cdot N_{sw}$$

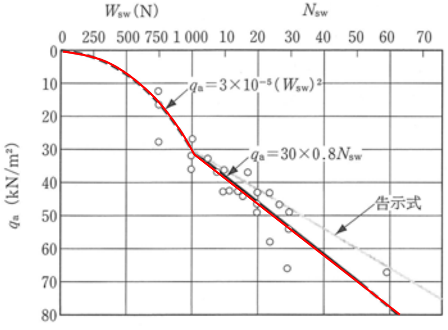
where

q_a : allowable bearing capacity (kN/m^2)

W_{sw} : the load in the case of penetration only by the load below 1000N (N)

N_{sw} : the numbers of half rotation per the 1m penetration after the penetration by the load of 1000N stopping (回/m)

Relationship between the bearing capacity by the plate bearing test and *W*sw, *N*sw



(b) relation with the bearing capacity after the ministry of Land Infrastructure and Transport, Japan

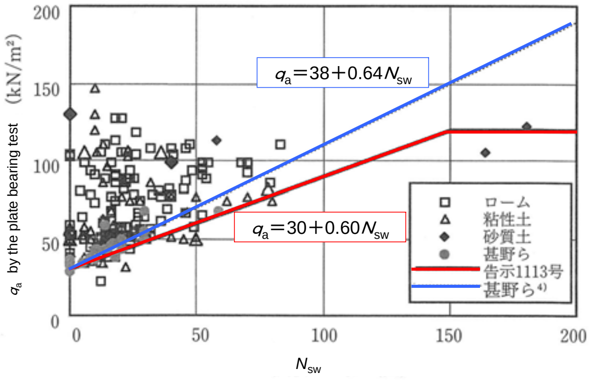
$$q_a = 30 + 0.6 \cdot N_{sw}$$

where

q_a : long-term allowable bearing capacity (kN/m^2)

N_{sw} : average value of the N_{sw} for soil layer within 2m under the bottom of the foundation

Relationship between q_a by the plate bearing test and N_{sw}



(d) relation with the bearing capacity formula

$$q_a = \alpha c N_c / F_s$$

where

α : shape factor ($\alpha = 1$)

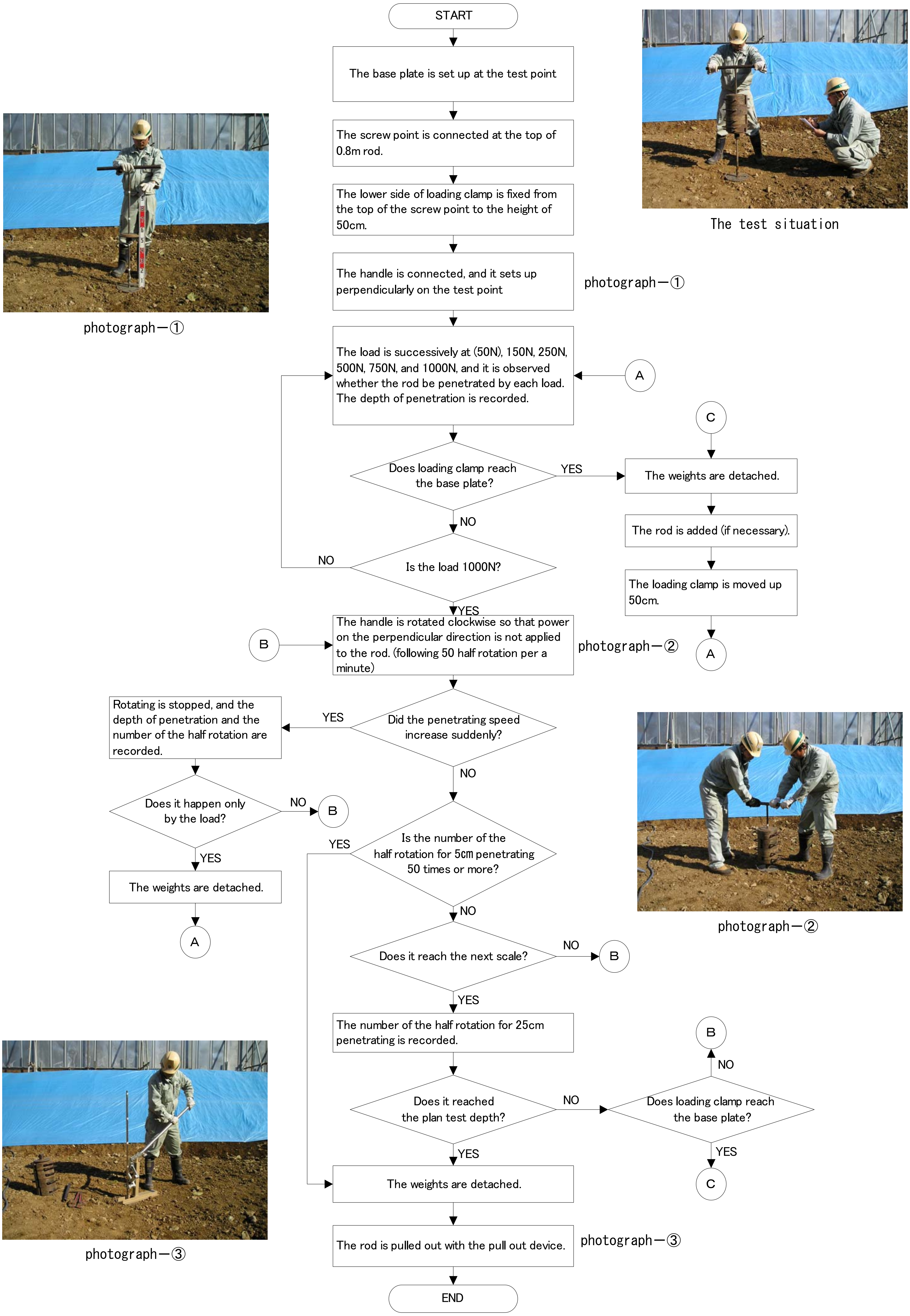
c : cohesion ($C = q_u/2$)

N_c : bearing capacity factor ($N_c = 5.1 \cdots \phi = 0°$)

F_s : safety factor ($F_s = 3$)

$$\begin{aligned} q_a &= 0.85 q_u \\ &= 0.85(0.045 W_{sw} + 0.75 N_{sw}) \\ &= 0.038 W_{sw} + 0.64 N_{sw} \end{aligned}$$

Liquefaction assessment can be conducted, that is very useful for reconstruction at the liquefieable area.



The test situation

photograph—①

photograph—②

photograph—③

Conversion table

weight Wsw (kN)	number of half rotation Na	length of penetration L=H (m)	Number of half rotation per 1m penetration Nsw	N value		unconfined compresive strength qu (kN/m^2)	allowable bearing capacity qa (kN/m^2)
				clay	sand		
0.05		0.25	0	0	0	2.3	1.5
0.15		0.25	0	0	0	6.8	4.5
0.25		0.25	0	1	1	11.3	7.5
0.50		0.25	0	2	1	22.5	15.0
0.75		0.25	0	2	2	33.8	22.5
1.00		0.25	0	3	2	45.0	30.0
1.00	1	0.25	4	3	2	48.0	32.4
1.00	2	0.25	8	3	3	50.9	34.7
1.00	3	0.25	12	4	3	53.9	37.1
1.00	4	0.25	16	4	3	56.9	39.5
1.00	5	0.25	20	4	3	59.8	41.9
1.00	6	0.25	24	4	4	62.8	44.2
1.00	7	0.25	28	4	4	65.8	46.6
1.00	8	0.25	32	5	4	68.7	49.0
1.00	9	0.25	36	5	4	71.7	51.3
1.00	10	0.25	40	5	5	74.6	53.7
1.00	11	0.25	43	5	5	77.6	56.1
1.00	12	0.25	47	5	5	80.6	58.5
1.00	13	0.25	51	6	5	83.5	60.8
1.00	14	0.25	55	6	6	86.5	63.2
1.00	15	0.25	59	6	6	89.5	65.6
1.00	16	0.25	63	6	6	92.4	67.9
1.00	17	0.25	67	6	7	95.4	70.3
1.00	18	0.25	71	7	7	98.4	72.7
1.00	19	0.25	75	7	7	101.3	75.1
1.00	20	0.25	79	7	7	104.3	77.4
1.00	22	0.25	87	7	8	110.2	82.2
1.00	24	0.25	95	8	8	116.1	86.9
1.00	26	0.25	103	8	9	122.1	91.7
1.00	28	0.25	111	9	9	128.0	96.4
1.00	30	0.25	119	9	10	133.9	101.1
1.00	32	0.25	126	9	10	139.9	105.9
1.00	34	0.25	134	10	11	145.8	110.6
1.00	36	0.25	142	10	12	151.7	115.4
1.00	38	0.25	150	11	12	157.6	120.1
1.00	40	0.25	158	11	13	163.6	124.9
1.00	42	0.25	166	11	13	169.5	129.6
1.00	44	0.25	174	12	14	175.4	134.3
1.00	46	0.25	182	12	14	181.4	139.1
1.00	48	0.25	190	12	15	187.3	143.8
1.00	50	0.25	198	13	15	193.2	148.6
1.00	52	0.25	206	13	16	199.2	153.3
1.00	54	0.25	213	14	16	205.1	158.1
1.00	56	0.25	221	14	17	211.0	162.8
1.00	58	0.25	229	14	17	216.9	167.5
1.00	60	0.25	237	15	18	222.9	172.3
1.00	62	0.25	245	15	18	228.8	177.0
1.00	64	0.25	253	16	19	234.7	181.8
1.00	66	0.25	261	16	19	240.7	186.5
1.00	68	0.25	269	16	20	246.6	191.3
1.00	70	0.25	277	17	21	252.5	196.0
1.00	72	0.25	285	17	21	258.4	200.8
1.00	74	0.25	292	18	22	264.4	205.5
1.00	76	0.25	300	18	22	270.3	210.2
1.00	78	0.25	308	18	23	276.2	215.0
1.00	80	0.25	316	19	23	282.2	219.7
1.00	82	0.25	324	19	24	288.1	224.5
1.00	84	0.25	332	20	24	294.0	229.2
1.00	86	0.25	340	20	25	299.9	234.0
1.00	88	0.25	348	20	25	305.9	238.7
1.00	90	0.25	356	21	26	311.8	243.4
1.00	92	0.25	364	21	26	317.7	248.2
1.00	94	0.25	372	22	27	323.7	252.9
1.00	96	0.25	379	22	27	329.6	257.7
1.00	98	0.25	387	22	28	335.5	262.4
1.00	100	0.25	395	23	28	341.4	267.2
1.00	102	0.25	403	23	29	347.4	271.9
1.00	104	0.25	411	24	30	353.3	276.6
1.00	106	0.25	419	24	30	359.2	281.4
1.00	108	0.25	427	24	31	365.2	286.1
1.00	110	0.25	435	25	31	371.1	290.9
1.00	112	0.25	443	25	32	377.0	295.6
1.00	114	0.25	451	26	32	382.9	300.4
1.00	116	0.25	458	26	33	388.9	305.1
1.00	118	0.25	466	26	33	394.8	309.8
1.00	120	0.25	474	27	34	400.7	314.6
1.00	122	0.25	482	27	34	406.7	319.3
1.00	124	0.25	490	28	35	412.6	324.1
1.00	126	0.25	498	28	35	418.5	328.8
1.00	128	0.25	506	28	36	424.4	333.6
1.00	130	0.25	514	29	36	430.4	338.3
1.00	132	0.25	522	29	37	436.3	343.0
1.00	134	0.25	530	29	37	442.2	347.8
1.00	136	0.25	538	30	38	448.2	352.5
1.00	138	0.25	545	30	39	454.1	357.3
1.00	140	0.25	553	31	39	460.0	362.0
1.00	142	0.25	561	31	40	465.9	366.8
1.00	144	0.25	569	31	40	471.9	371.5
1.00	146	0.25	577	32	41	477.8	376.2
1.00	148	0.25	585	32	41	483.7	381.0
1.00	150	0.25	593	33	42	489.7	385.7
1.00	152	0.25	601	33	42	495.6	390.5
1.00	154	0.25	609	33	43	501.5	395.2
1.00	156	0.25	617	34	43	507.5	400.0
1.00	158	0.25	625	34	44	513.4	404.7
1.00	160	0.25	632	35	44	519.3	409.4
1.00	162	0.25	640	35	45	525.2	414.2
1.00	164	0.25	648	35	45	531.2	418.9
1.00	166	0.25	656	36	46	537.1	423.7
1.00	168	0.25	664	36	46	543.0	428.4
1.00	170	0.25	672	37	47	549.0	433.2
1.00	172	0.25	680	37	48	554.9	437.9
1.00	174	0.25	688	37	48	560.8	442.6
1.00	176	0.25	696	38	49	566.7	447.4
1.00	178	0.25	704	38	49	572.7	452.1
1.00	180	0.25	711	39	50	578.6	456.9
1.00	182	0.25	719	39	50	584.5	461.6
1.00	184	0.25	727	39	51	590.5	466.4
1.00	186	0.25	735	40	51	596.4	471.1
1.00	188	0.25	743	40	52	602.3	475.8
1.00	190	0.25	751	41	52	608.2	480.6
1.00	192	0.25	759	41	53	614.2	485.3
1.00	194	0.25	767	41	53	620.1	490.1
1.00	196	0.25	775	42	54	626.0	494.8
1.00	198	0.25	783	42	54	632.0	499.6
1.00	200	0.25	791	43	55	637.9	504.3
1.00	202	0.25	798	43	55	643.8	509.1
1.00	204	0.25	806	43	56	649.7	513.8
1.00	206	0.25	814	44	57	655.7	518.5
1.00	208	0.25	822	44	57	661.6	523.3
1.00	210	0.25	830	45	58	667.5	528.0
1.00	212	0.25	838	45	58	673.5	532.8
1.00	214	0.25	846	45	59	679.4	537.5
1.00	216	0.25	854	46	59	685.3	542.3
1.00	218	0.25	862	46	60	691.2	547.0
1.00	220	0.25	870	46	60	697.2	551.7
1.00	222	0.25	877	47	61	703.1	556.5
1.00	224	0.25	885	47	61	709.0	561.2
1.00	226	0.25	893	48	62	715.0	566.0
1.00	228	0.25	901	48	62	720.9	570.7
1.00	230	0.25	909	48	63	726.8	575.5
1.00	232	0.25	917	49	63	732.7	580.2
1.00	234	0.25	925	49	64	738.7	584.9
1.00	236	0.25	933	50	64	744.6	589.7
1.00	238	0.25	941	50	65	750.5	594.4
1.00	240	0.25	949	50	66	756.5	599.2
1.00	242	0.25	957	51	66	762.4	603.9
1.00	244	0.25	964	51	67	768.3	608.7
1.00	246	0.25	972	52	67	774.2	613.4
1.00	248	0.25	980	52	68	780.2	618.1

Examples of liquefaction and damage due to liquefaction

When an earthquake, of which intensity exceeds a certain level, occurs, the excess pore water pressure generates (Fig.1[1)]). Liquefaction is caused by losing its shear resistance due to the decreases of effective stress. Various damages[2)] to soil and structure are induced due to the liquefaction (Photo 1-4). The examples are as follows:

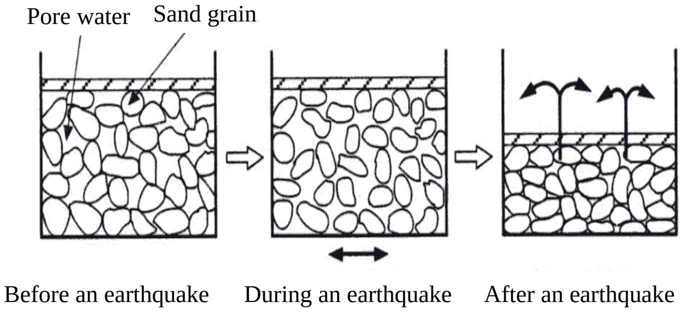


Fig.1 Schematic figure of liquefaction mechanism[1)]

Photo 1 Liquefaction induced damage to buildings in Gunun Sitoli[2)]

Photo 2 Liquefaction induced damage to buildings in Gunun Sitoli[2)]

Photo 3 Lateral spreading due to liquefaction[2)]

Photo 4 Sandboil[2)]

Assessment of shaking intensity of input ground motion

Liquefaction potential depends on the intensity of shaking. Seismic coefficient in Indonesia is shown in Fig.2 and 3[3)]. In case that the average response spectrum in the target site can be used as in Japan, the corresponding acceleration expected (Fig.4) is easily obtained by the following regression equation[4)].

$$S_A(T_k, M, \Delta, GC_i) = a(T_k, GC_i) \times 10^{b(T_k, GC_i) \cdot M} \times (\Delta + 30)^{c(T_k, GC_i)} \quad (1)$$

in which M is magnitude, Δ epicentral distance, GC ground condition, T natural period of structure.

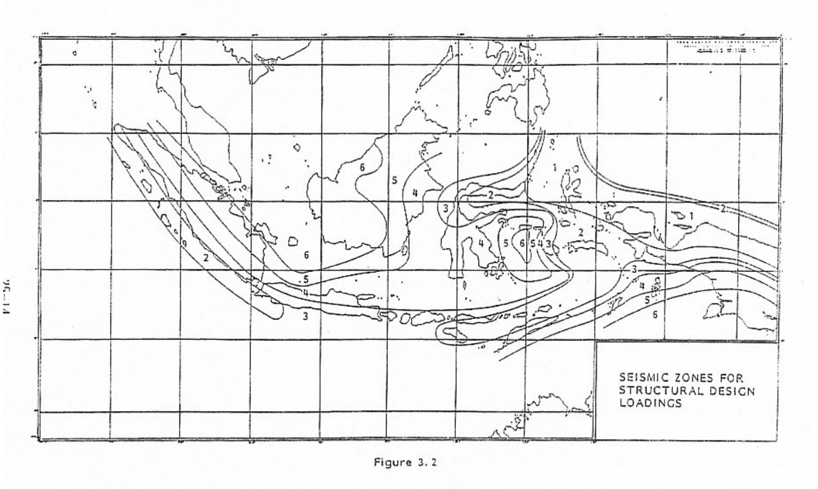


Fig.2 Seismic zoning in indnesia[3)]

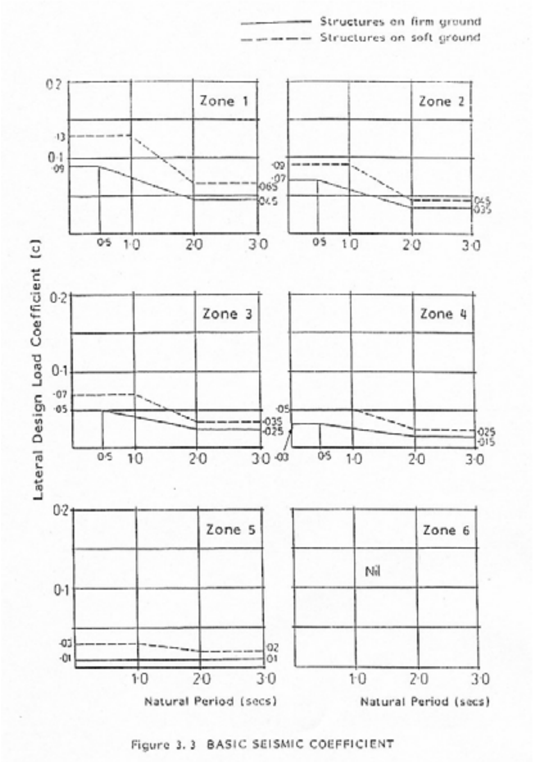
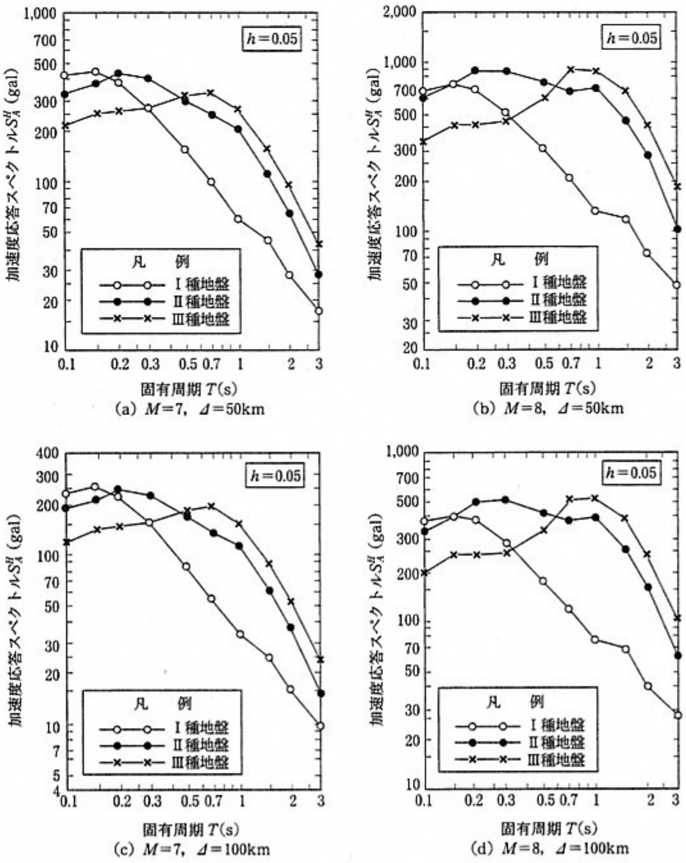


Fig.3 Seismic coefficient[3)]



(a) $M=7$, $\Delta=50$km　(b) $M=8$, $\Delta=50$km

(c) $M=7$, $\Delta=100$km　(d) $M=8$, $\Delta=100$km

図-参 2.7　水平成分加速度応答スペクトル

Fig.4 Examples of horizontal response acceleration in Japan[4)]

Liquefaction susceptibility based on existing data[5)]

Liquefaction is known to occur repeatedly at the same site. Thus maps showing the localities of past liquefaction may be considered as potential areas of liquefaction in future earthquake. In particular, if a correlation is established between past liquefaction occurrence and geological and geomorphological criteria, then this may be used to infer the likely area of liquefaction susceptibility. An example of this was reported by Iwasaki et al. who analyzed several dozen of Japanese earthquakes and developed the criteria listed in Table 1. Fig.5 shows an example of mapping based on the correlation for an area in Japan, where a large magnitude 8 earthquake anticipated in the near future.

Fig. 6 expresses the grain size accumulation curves, in which the possibility of liquefaction is shown. The soil with small grain size such as clay has cohesion, therefore, liquefaction will seldom occur even if the pore water pressure increases and effective confining pressure becomes zero. For the soil with large grain size such as gravel, the liquefaction will not occur because of the good drainage.

Table 1 Susceptibility of geomorphological units to liquefaction[5)]

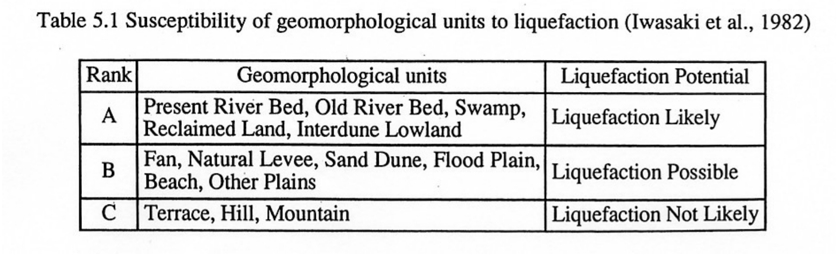


Table 5.1 Susceptibility of geomorphological units to liquefaction (Iwasaki et al., 1982)

Rank	Geomorphological units	Liquefaction Potential
A	Present River Bed, Old River Bed, Swamp, Reclaimed Land, Interdune Lowland	Liquefaction Likely
B	Fan, Natural Levee, Sand Dune, Flood Plain, Beach, Other Plains	Liquefaction Possible
C	Terrace, Hill, Mountain	Liquefaction Not Likely

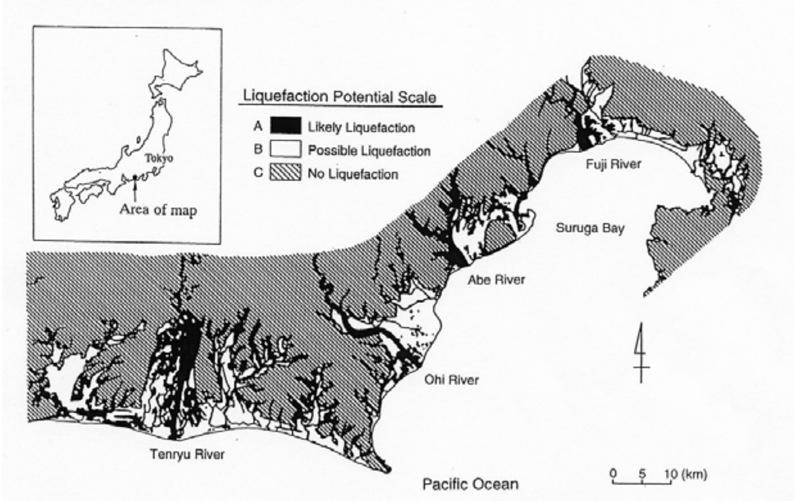


Fig.5.3 Microzonation map of liquefaction potential estimated from geomorphological information (Iwasaki et al., 1982)

Fig. 5 Microzonation map of liquefaction potential[5)]

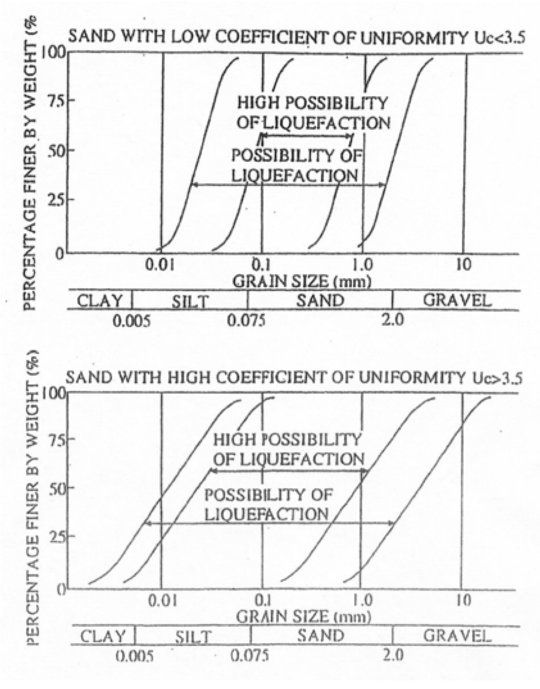


Fig.6 Grain size accumulation curves[6)]

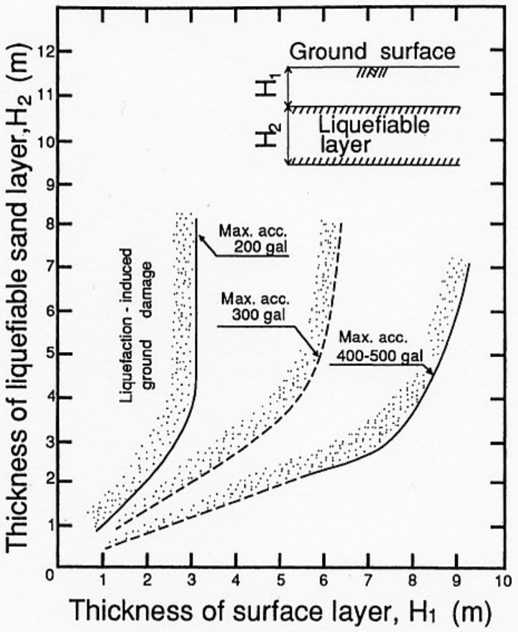


Fig. 5.17 Proposed boundary curves for surface manifestation of liquefaction-induced damage (Ishihara, 1985)

Fig.7 Relation between thickness of the liquefiable layer and thickness of surface layer[5)]

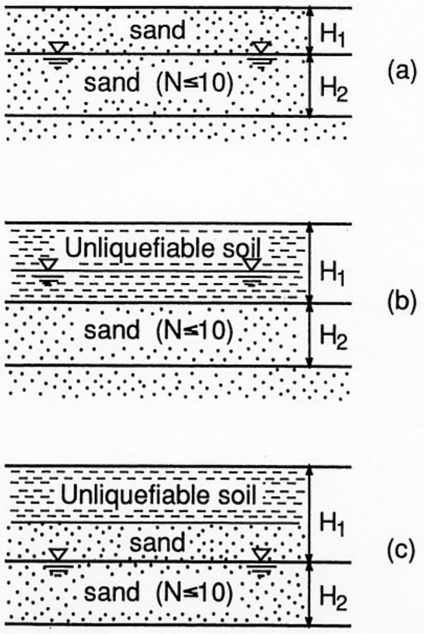


Fig. 5.18 Definitions of the surface unliquefiable layer and the underlying liquefiable sand layer (Ishihara, 1985)

Fig.8 Definition of H_1 and H_2 [5)]

Damage in the presence of an unliquefiable surface layer or crust[5)]

To decide whether liquefaction will or will not exert damage on the ground surface, the thickness of the liquefiable layer can be compared with the thickness of the surface crust using criteria such as that shown in Fig.7. If the thickness of the surface layer, H_1, is larger than that of the underlying liquefied layer, resulting damage on the ground surface may be significant. If the water table is below the ground surface the definition of H_1 depends on the nature of the superficial deposit, as shown in Fig.8. For a deposit of sandy soil, the thickness of H_1 can be taken to be equal to the depth of the water table.

Judgment and countermeasure for liquefaction

Judgment for liquefaction

To evaluate the occurrence of liquefaction is important to consider the stability of structures on the ground.

Prediction methods for liquefaction are divided into two types; 1) judge that liquefaction will finally occur or not, 2) predict the occurrence of liquefaction including the liquefaction process during an earthquake.

In this report, we show one of the former techniques proposed by Seed and Idriss[7)]. Index is called FL-value (F_L). In this method, magnitude (expected peak acceleration), underground water level, and N-value are needed. The procedure[1)] to determine F_L is
(1) Assuming the peak acceleration of the surface ground, α_{max}, equivalent cyclic shear stress ratio, L, in each soil layer during an earthquake is calculated as

$$L = \tau_d / \sigma'_v \tag{2}$$

in which τ_d is the shear stress generated during an earthquake, and σ_v' the effective overburden pressure. Eq.(2) is rewritten as

$$\begin{aligned} L = \tau_d / \sigma'_v &= 0.65 \frac{\alpha_{\max}}{g} \gamma_d \ \sigma_v / \sigma'_v \\ &= 0.65 \frac{\alpha_{\max}}{g} \frac{\sigma_v}{\sigma'_v} \gamma_d \end{aligned} \tag{3}$$

in which g is gravity, σ_v the total overburden stress in each layer, and γ_d a stress reduction factor of the overburdening stress, which depends on the depth, z, as follows.

$$\gamma_d = 1 - z/90 \tag{4}$$

(2) Liquefaction resistance stress ratio, R, is calculated by using N-value, effective vertical overburden, and earthquake magnitude. Modified N-value, N_1, is obtained from the N-value and effective vertical overburden by using the relation between σ_v' and C_N as shown in Fig.9.

$$N_1 = C_N\ N \qquad (5)$$

Liquefaction resistance stress ratio, R, can be obtained by making the obtained modified N-value, N_1, for each layer correspond to the earthquake magnitude. The relation between $R=\tau_l/\sigma_v'$ and N_1 is shown in Fig. 10.

(3) Compare the value of R with that of L. Liquefaction does not occur if R>L, otherwise liquefaction occurs. This ratio of R and L is defined as the liquefaction resistant factor, F_L. F_L expresses a safety factor for liquefaction.

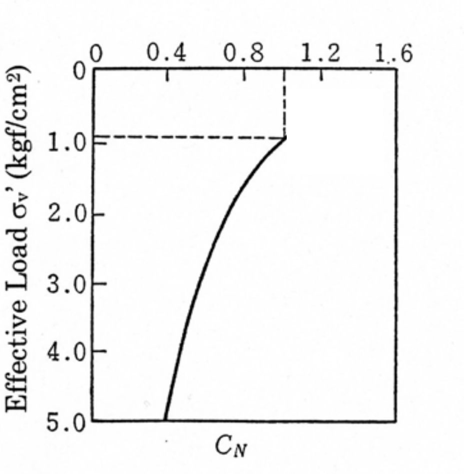


Fig.9 Relation between modified N-value and coefficient, C_N

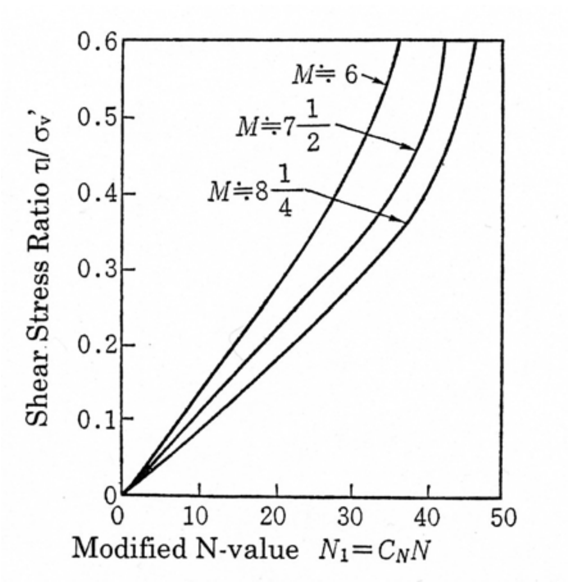


Fig.10 Relation between modified N-value and liquefaction resistance stress ratio

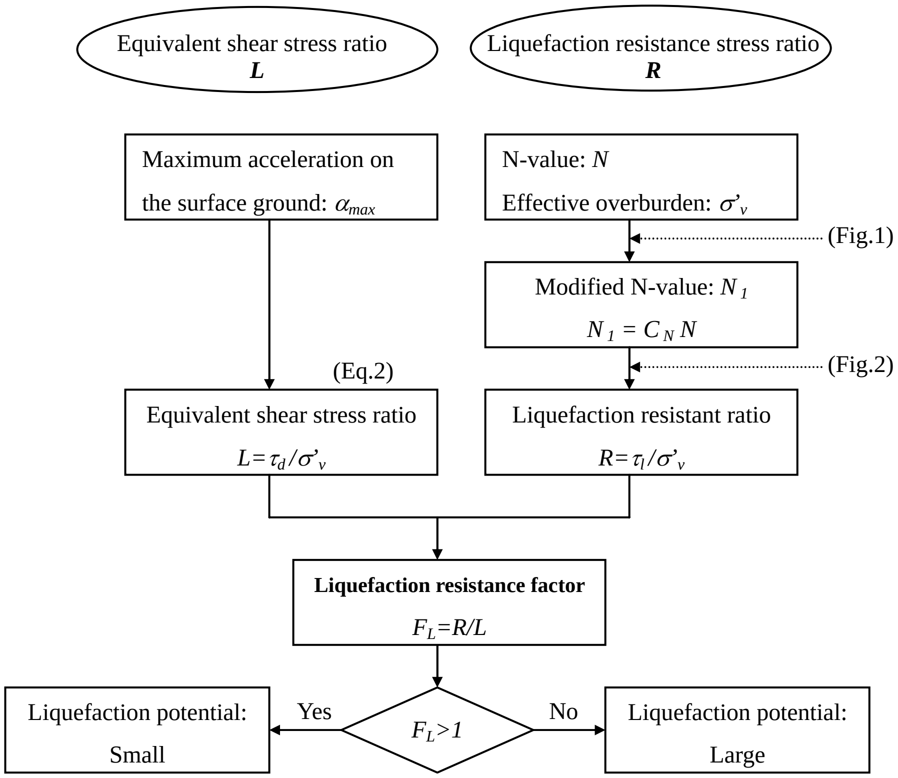


Fig.11 Flow chart of the simplified liquefaction judgment technique

Above procedure compiled in Fig.11 is the simplest judging method for the soil liquefaction capacity, however, more detailed procedure is popular in case that the result of laboratory test (ex. tri-axial compression test) can be utilized.

Measures for preventing or reducing liquefaction

When we take the countermeasure for liquefaction, we have to consider such factors as soil conditions, scale of the structure, the value of the structure, and so on.

Countermeasures for liquefaction are roughly divided into three categories;

(1) Construct a structure at the place where liquefaction potential is low

In case that a structure is important and alternative enough space exists, a location issue should be taken into account.

(2) Permit the occurrence of liquefaction, however, the structure is strengthened to avoid the liquefaction-induced structural damage.

In case that the ground can not be improved by some reasons, the structure itself is strengthened in order to decrease damage although the occurrence of liquefaction is permitted. Installing piles is an example. Strengthening of the structure by introducing braces is also a possible solution. These measures are depending on a structure type.

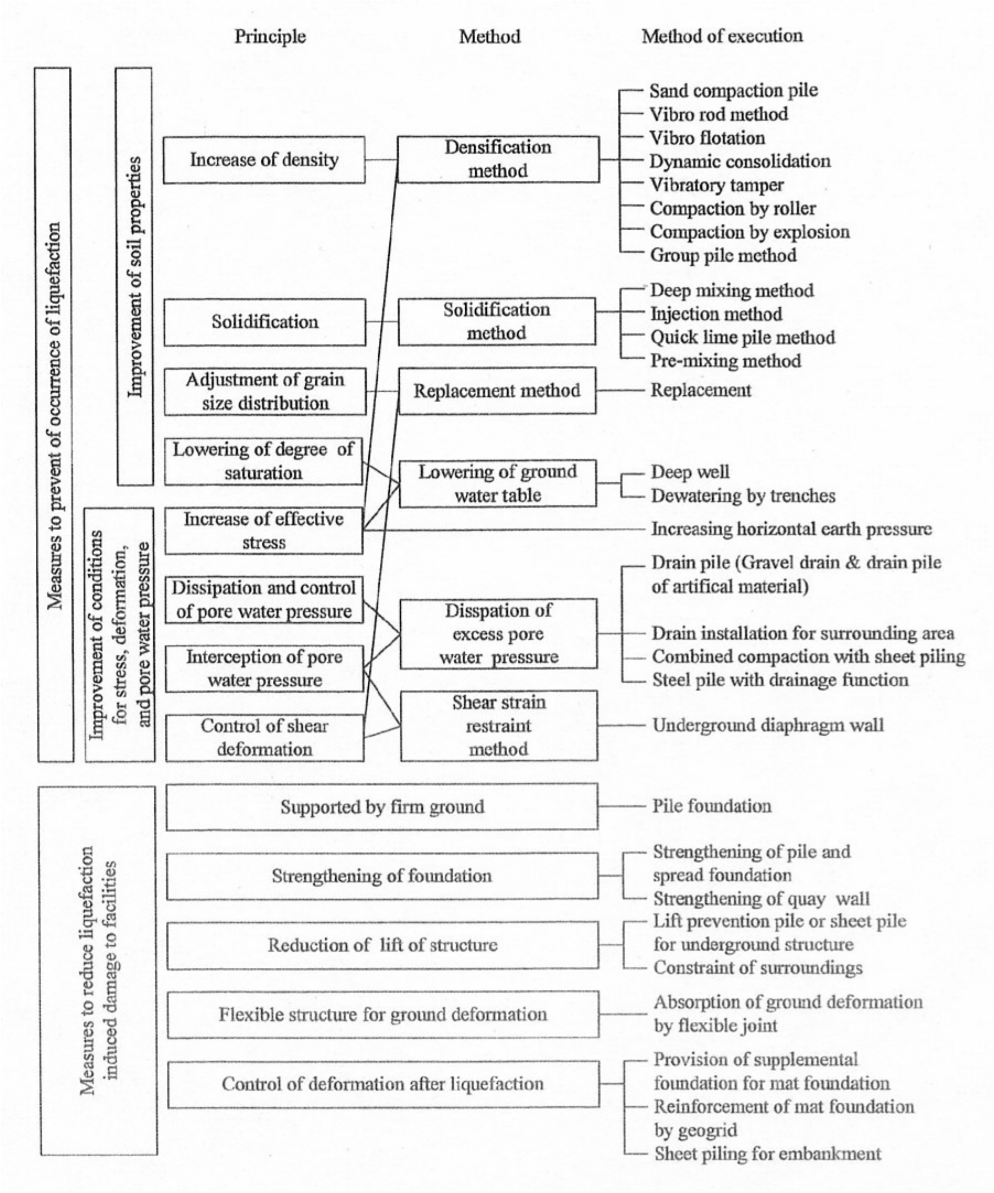


Fig.12 Various anti-liquefaction measures

(3) To prevent the occurrence of liquefaction, liquefaction-proof countermeasures are taken.

This is realized by decreasing shear stress during an earthquake, or by increasing a resistance force. Many construction methods for preventing of liquefaction occurrence or reducing liquefaction are developed (Fig.12), however, their basic principles are

(a) Increase density of sand layer

Sand layer is compacted by adding impact or vibration

(b) Reduce groundwater level/Increase effective stress

Groundwater is reduced by well

(c) Improve grain size

Soil is replaced with large grain-size one

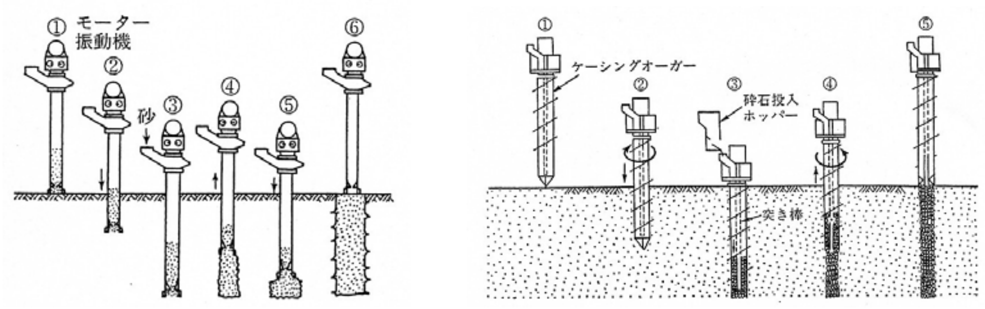
(d) Disperse pore water pressure

Gravel piles are installed to shorten drain path

(e) Restrain shear deformation

Drive sheet piles or construct underground continuous wall

Examples of anti-liquefaction construction method for (a) and (d) are shown in Fig.12.



(a) sand compaction pile

(d) gravel drain

Fig. 12 Examples of anti-liquefaction construction method

References

1) JSSMFE: Textbook for Earthquake and Earthquake Resistance for Soil and Foundation Engineering, pp.126-128, 1985 (in Japanese).

2) JSCE: A tentative report of the support team of Japan Society of Civil Engineers for the restoration and rehabilitation of infrastructures and buildings damaged by the M8.7 Nias earthquake of march 28, 2005 in Nias island, Indonesia, 2005.

3) World List:

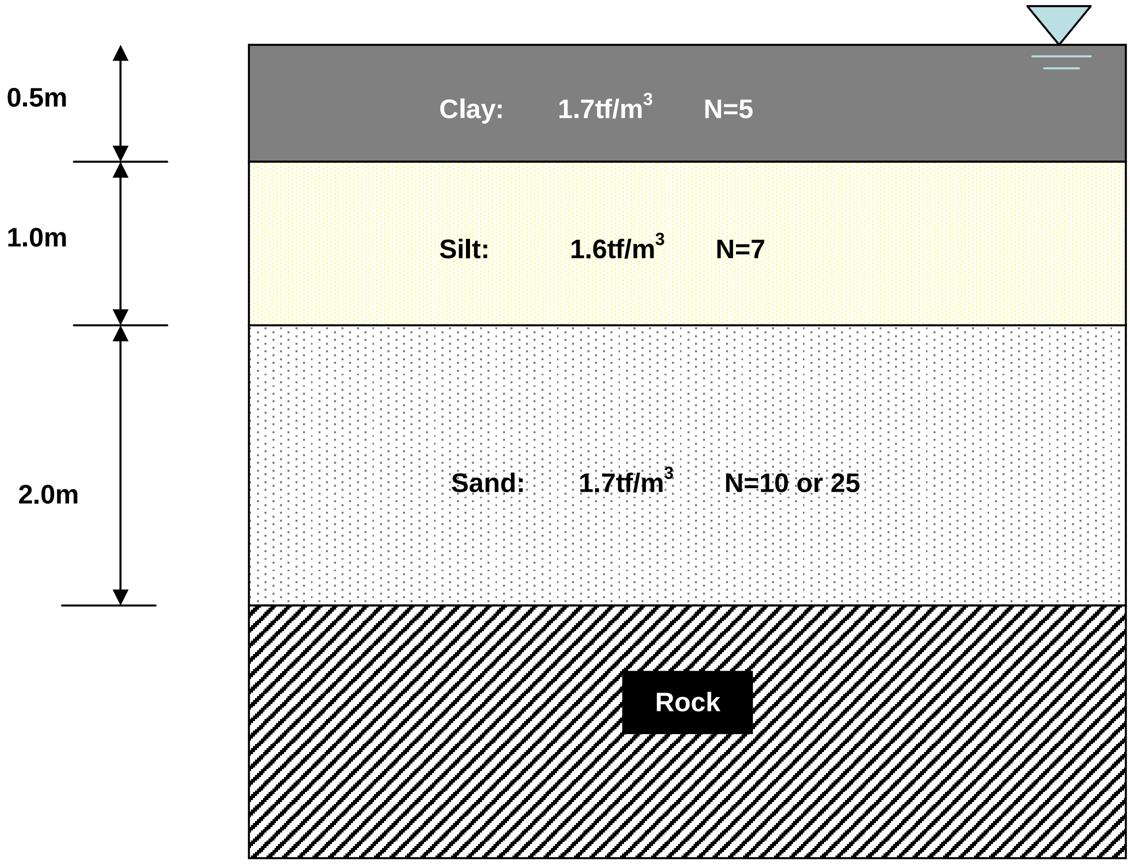
4) Japan Road Association: Specification for Highway Bridge, Part V earthquake Resistant Design, 2003.

5) JSSMFE: Manual for Zonation on Seismic Geotechnical Hazards, December, 1993.

6) Kowan:

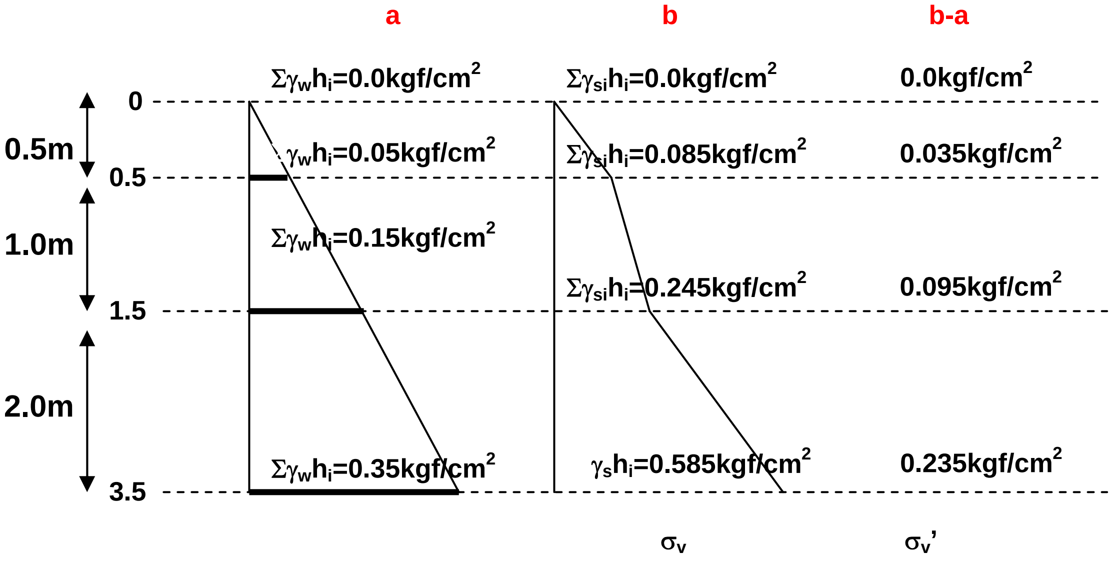
7) Seed, H.B. and Idriss, I.M.: Simplified Procedure for evaluation Soil Liquefaction Potential, J.SMFD, ASCE, Vol.97, No.9, pp.1249-1273, 1971.

Example



$$L=\tau_d/\sigma'_v=0.65\frac{\alpha_{\max}}{g}\frac{\sigma_v}{\sigma'_v}\gamma_d$$

α_{max}/g=0.1 assumed

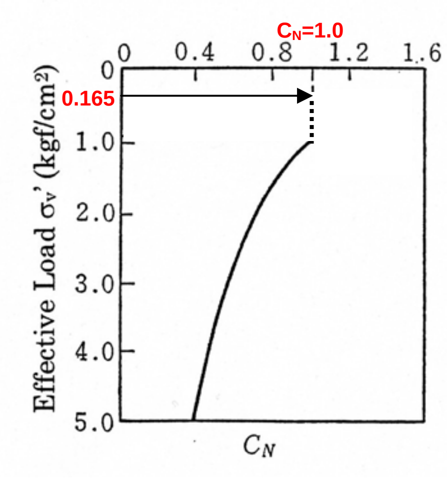


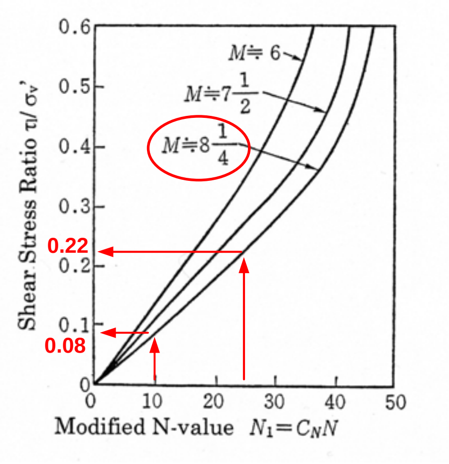
$$\gamma_d=1-z/90=1-2.5/90=0.972$$

$$L=0.65\times0.1\times0.415/0.165\times0.972=0.16$$

$$L=0.16$$

	b	b-a	Average b*	Average (b-a)*
0	$\Sigma\gamma_{si}h_i=0.0\text{kgf/cm}^2$	0.0kgf/cm^2		
0.5	$\Sigma\gamma_{si}h_i=0.085\text{kgf/cm}^2$	0.035kgf/cm^2	○ 0.0425	0.0175
2.5m			○ 0.165	0.065
1.5	$\Sigma\gamma_{si}h_i=0.245\text{kgf/cm}$	0.095kgf/cm^2		
			○ 0.415	0.165
3.5	$\Sigma\gamma_{s}h_i=0.585\text{kgf/m}^2$	0.235kgf/cm^2		
	σ_v	σ_v'	σ_v	σ_v'



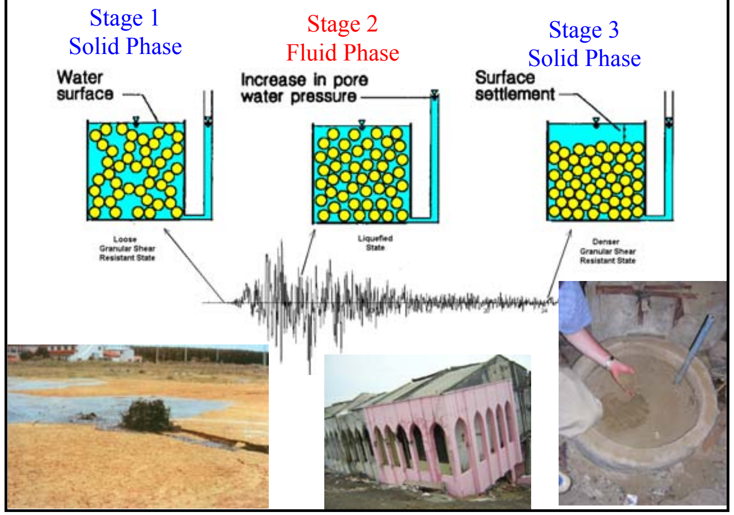


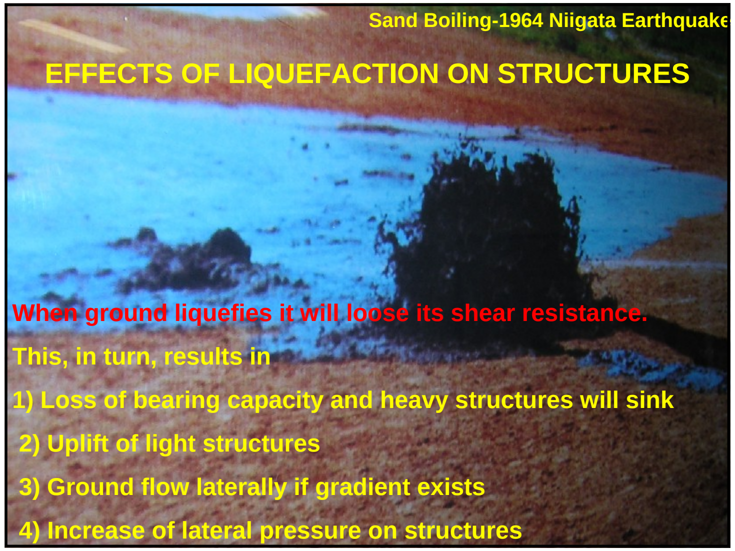
Now we here assume that the magnitude is 8.25.

If N=10 then N1=1.0x10=10, so R=0.08. R/L=0.08/0.16<1: Liquefaction

If N=25 then N1=1.0x25=25, so R=0.22. R/L=0.22/0.16>1: No liquefaction

GROUND LIQUEFACTION





EFFECTS OF LIQUEFACTION ON STRUCTURES

When ground liquefies it will loose its shear resistance.

This, in turn, results in

1) Loss of bearing capacity and heavy structures will sink
2) Uplift of light structures
3) Ground flow laterally if gradient exists
4) Increase of lateral pressure on structures

EFFECTS OF LIQUEFACTION ON BUILDINGS

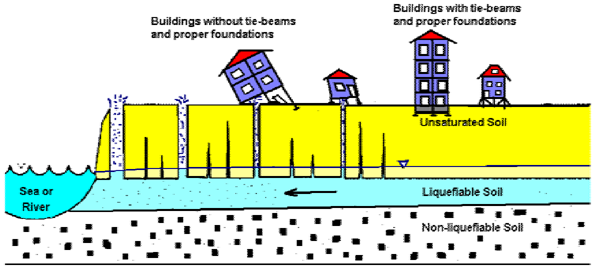
Settlement + Tilting

Lateral Spreading

WOODEN BUILDINGS

Settlement & Lateral Spreading(No tie-beams or diagonal members

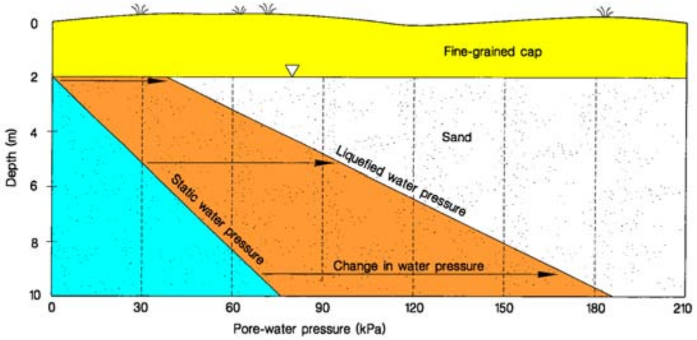
EFFECT OF LATERAL SPREADING ON BUILDINGS WITH OR WITHOUT TIE-BEAMS

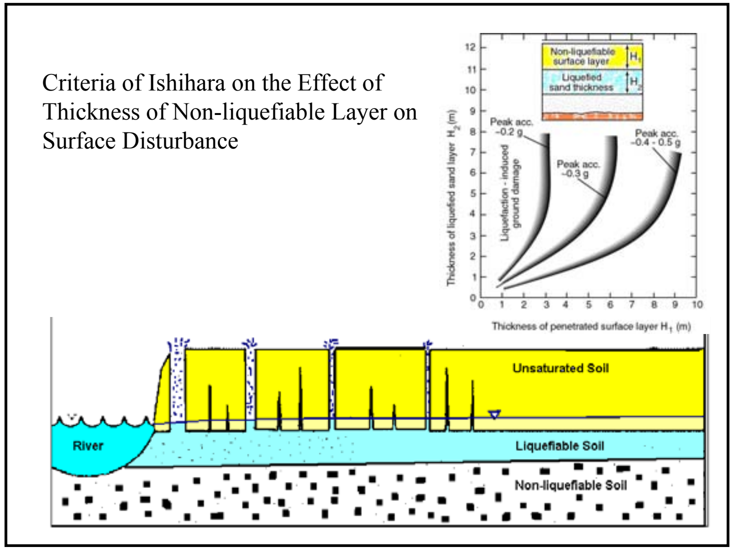


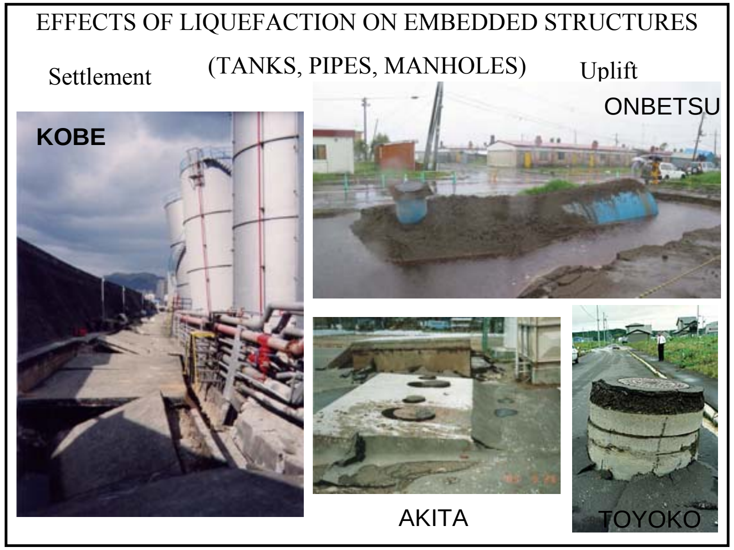
EFFECTS OF LIQUEFACTION ON RETAINING & QUAY WALLS

Settlement + Lateral spreading + Tilting

Illustration of Water Pressure Increase due to Liquefaction




Criteria of Ishihara on the Effect of Thickness of Non-liquefiable Layer on Surface Disturbance


EFFECTS OF LIQUEFACTION ON EMBEDDED STRUCTURES

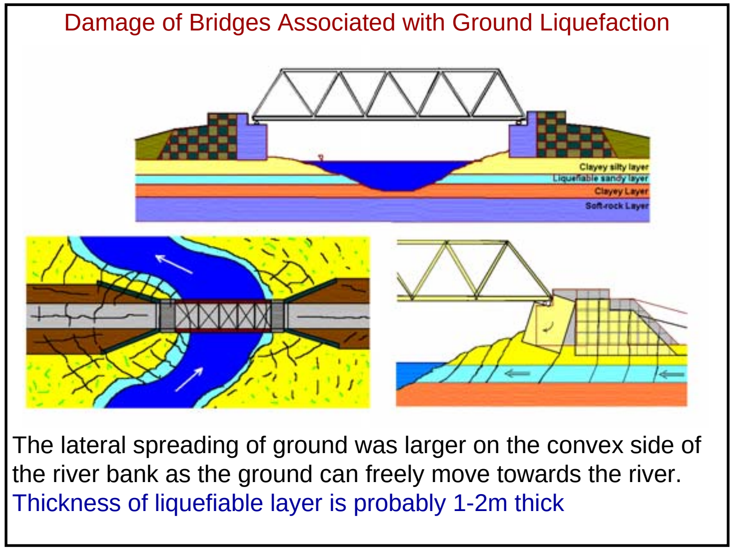
(TANKS, PIPES, MANHOLES)

Settlement

Uplift


EFFECTS OF LIQUEFACTION ON BRIDGE FOUNDATIONS

Settlement & Tilting & Lateral Movement


Damage of Bridges Associated with Ground Liquefaction

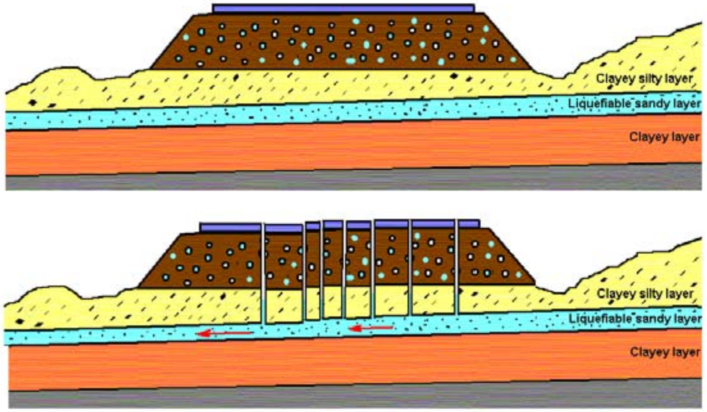
The lateral spreading of ground was larger on the convex side of the river bank as the ground can freely move towards the river.

Thickness of liquefiable layer is probably 1-2m thick

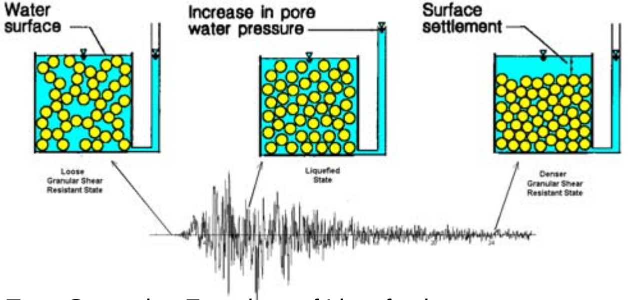
EFFECTS OF LIQUEFACTION ON ROADWAY EMBANKMENTS

Settlement & Lateral Spreading

CAUSES OF ROADWAY DAMAGE



GROUND LIQUEFACTION



Biot Type Governing Equations of Liquefaction

Solid Phase $\nabla \cdot (1-n)\boldsymbol{\sigma}_s + (1-n)\rho_s g = (1-n)\rho_s \ddot{\mathbf{u}}_s - \boldsymbol{\xi}_{sf}$

Fluid Phase $\nabla \cdot n\boldsymbol{\sigma}_f + n\rho_f g = n\rho_f \ddot{\mathbf{u}}_f + \boldsymbol{\xi}_{sf}$

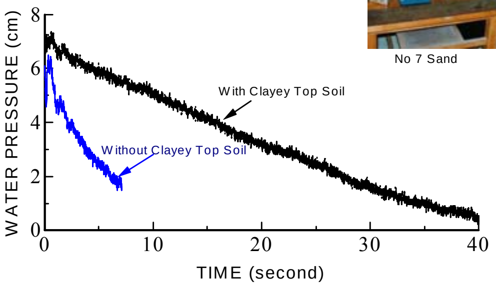
Coupling $\boldsymbol{\xi}_{sf} = -n\frac{\eta}{k}\mathbf{v}_r$ $\boldsymbol{\sigma} = \boldsymbol{\sigma}' - \mathbf{p}$

Liquefaction State $\boldsymbol{\sigma}' = \mathbf{0}$

Liquefaction depends entirely on Shear resistance & Permeability

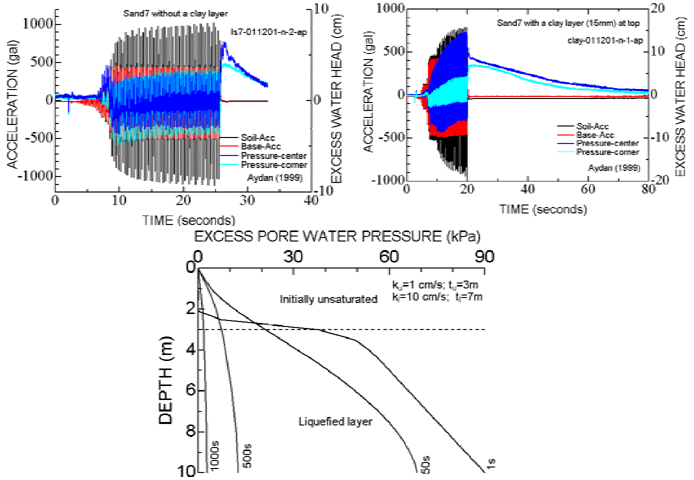
Effect of Clayey Top Soil

No 7 Sand



Existence of top non-permeable layer will prolong liquefaction state

EFFECT OF IMPERMEABLE NON-LIQUEFIED SOIL LAYER ON PROLONGATION OF LIQUEFACTION STATE



Assessment of Liquefaction Potential

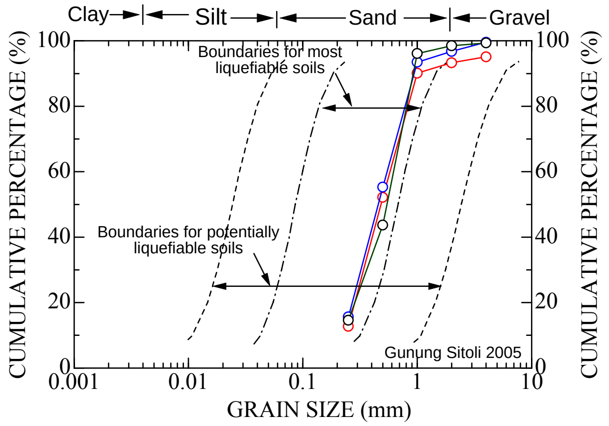
Empirical Methods(based on mainly SPT N-Values)

- ➢Grain-size method
- ➢Magnitude-distance method
- ➢Seed-Idriss
- ➢Yoshimi-Tokimatsu
- ➢Ambraseys
- ➢Japan Roadway and Bridges Society
- ➢Youd et al.

Numerical Methods (mainly Biot-type) (Zienkiewicz et al., Shiomi)

- U-U Formulation
- U-P Formulation

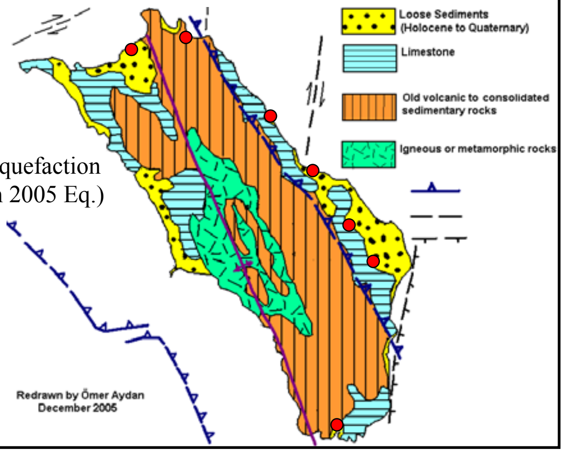
Grain Size Distribution Approach



Geological Criteria for Liquefaction Assessment

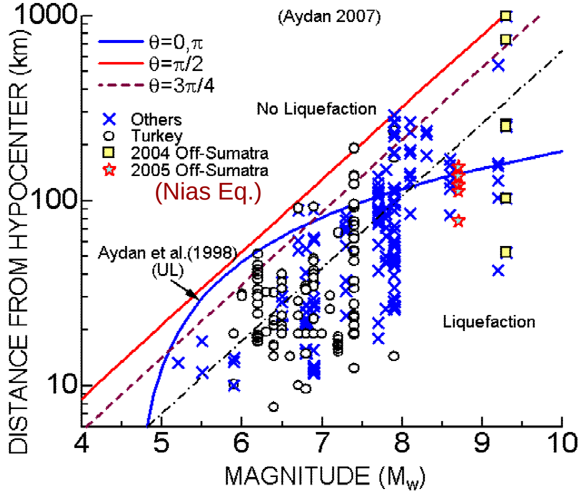
Holocene to Quaternary sedimentary deposits

Seismic Zoning



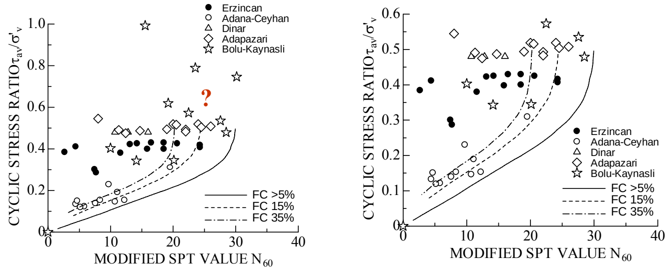
● Observed Liquefaction Sites (March 2005 Eq.)

Distance-Magnitude Relations for Liquefaction Limits



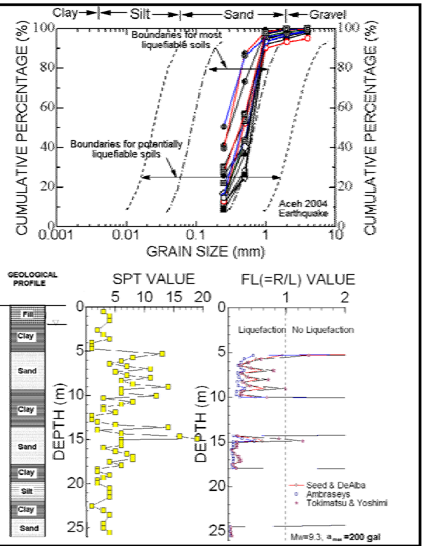
Conventional Procedures

- •Maximum Ground Acceleration (Function of Magnitude)
- •Ground Resistance (SPT N (recently CPT, Vs, Swedish CPT etc.))

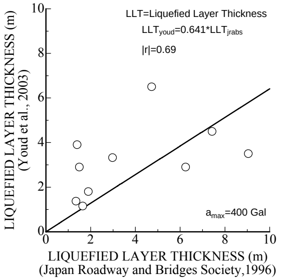


Seed's charts are insufficient if maximum ground acceleration, fine content are considered. Furthermore, the conventional methods lacks one of the most important parameter of the liquefaction phenomenon

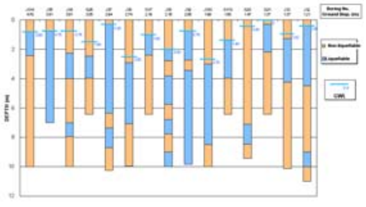
BANDA
ACEH



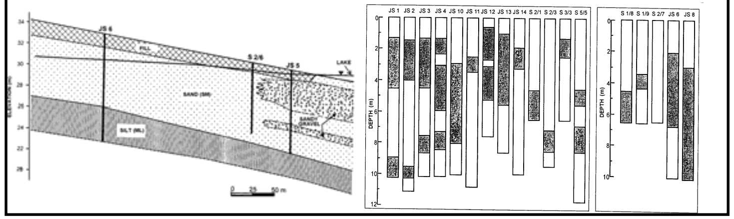
Liquefaction Susceptibility Analysis



Japan Roadway and Bridges Society (Inuzuka)

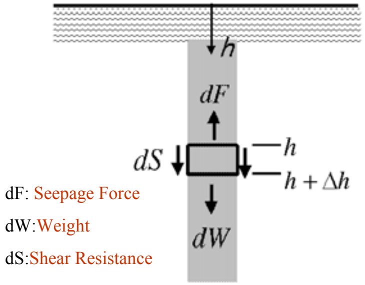


According to Youd et al. (2001) by Kanıbir)



The Method of Aydan & Kumsar (1997) for Liquefaction Susceptibility Assessment

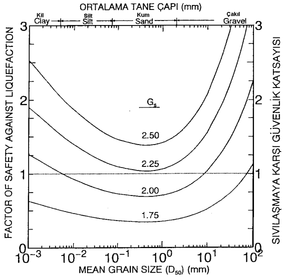
- **Maximum Ground Acceleration (Function of Magnitude)**
- **Cohesion and Friction Angle (Function of Grain Size). They may also be inferred from (SPT N (recently CPT, Vs etc.))**
- **Permeability (Function of Grain Size & Grain Size Distribution)**



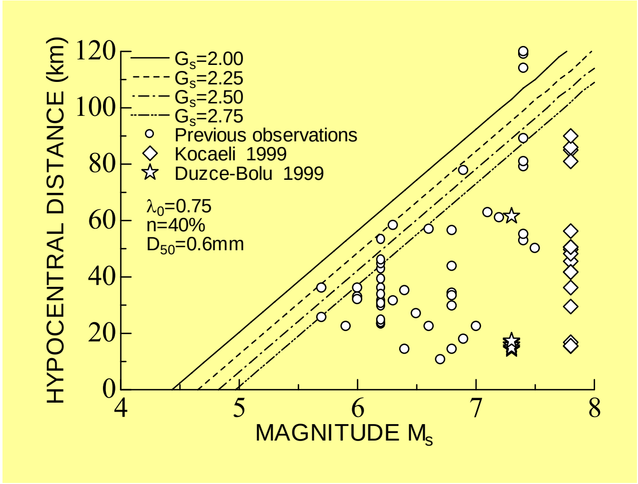
dF: Seepage Force

dW:Weight

dS:Shear Resistance



Estimation of Liquefaction Limits as a Function of Magnitude



Lateral Spreading Evaluations

1) Empirical Methods

Hamada et al. (1986), MLR of Youd et al. (2003), Bardet et al. (1999)

2) **Sliding Body Method** (based on Newmark Method)

(i.e.Dobry and Baziar, 1992, Aydan et al. 2005)

3) **Numerical Methods**

Single Phase Method (Elastic, Elasto-Plastic, Visco-elastic)

(Yasuda(1990), Towhata (1992), Aydan (1994, 1995, 1997)

Mixture Models (mainly Biot-type) (Zienkiewicz et al., Shiomi)

- U-U Formulation
- U-P Formulation

Empirical Methods

Hamada et al.'s method(Inuzuka)

$$D = 0.75\ H^{0.5}\ \theta^{0.33} \qquad D_H = \frac{0.0125\,(H)^{0.5}\ \theta}{\overline{N}^{0.88}} \sum a_i^{\ 0.48}\ T_i$$

Youd et al.'s method(Kanıbir)

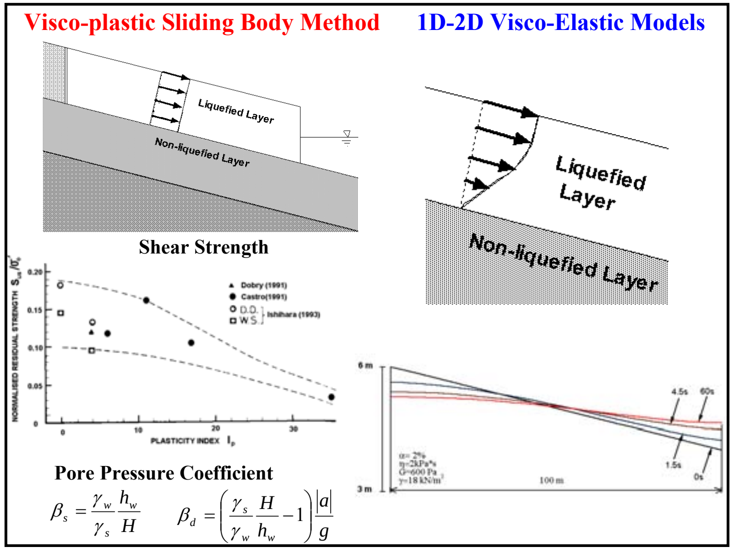
$$\mathrm{Log}D_H = -16.713 + 1.532M_w - 1.406\log R^* - 0.012R + 0.592\log W + 0.540\ \log T_{15} + 3.413\log\,(100\text{-}F_{15}) - 0.795\log(D50_{15} + 0.1)$$

Bardet et al.'s method(Kanıbir)

$$\log(D_H + 0.01) = b_0 + b_{off} + b_1M + b_2\log(R) + b_3R + b_4\log(W) + b_5\log(S) + b_6\log(T_{15}) + b_7\log(100\text{-}F_{15}) + b_8D50_{15}$$

Aydan et al. (2005)

$$\delta = \frac{\gamma_s H_l^2}{G}\sin\theta\ v_{\max}$$

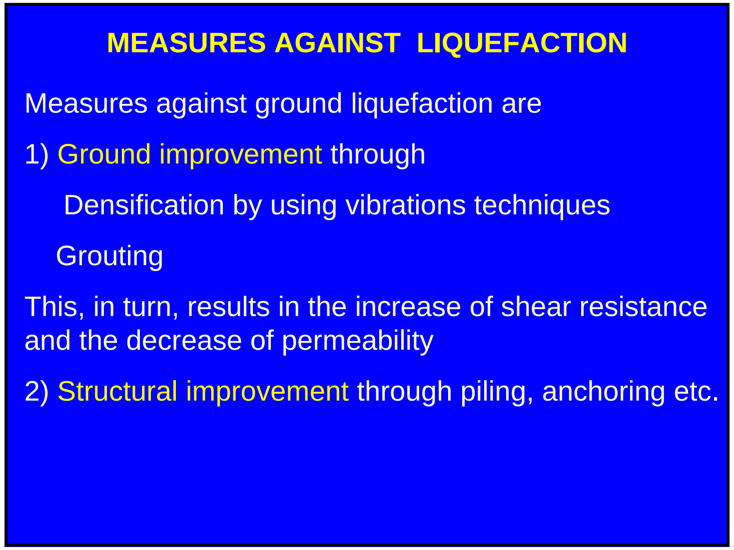


Visco-plastic Sliding Body Method **1D-2D Visco-Elastic Models**

Shear Strength

Pore Pressure Coefficient

$$\beta_s = \frac{\gamma_w}{\gamma_s}\frac{h_w}{H} \qquad \beta_d = \left(\frac{\gamma_s}{\gamma_w}\frac{H}{h_w} - 1\right)\frac{|a|}{g}$$



MEASURES AGAINST LIQUEFACTION

Measures against ground liquefaction are

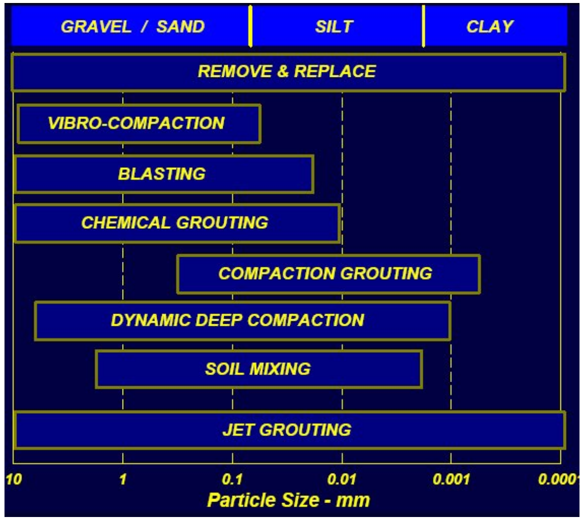
1) Ground improvement through

Densification by using vibrations techniques

Grouting

This, in turn, results in the increase of shear resistance and the decrease of permeability

2) Structural improvement through piling, anchoring etc.



GRAVEL / SAND | SILT | CLAY

REMOVE & REPLACE

VIBRO-COMPACTION

BLASTING

CHEMICAL GROUTING

COMPACTION GROUTING

DYNAMIC DEEP COMPACTION

SOIL MIXING

JET GROUTING

Particle Size - mm

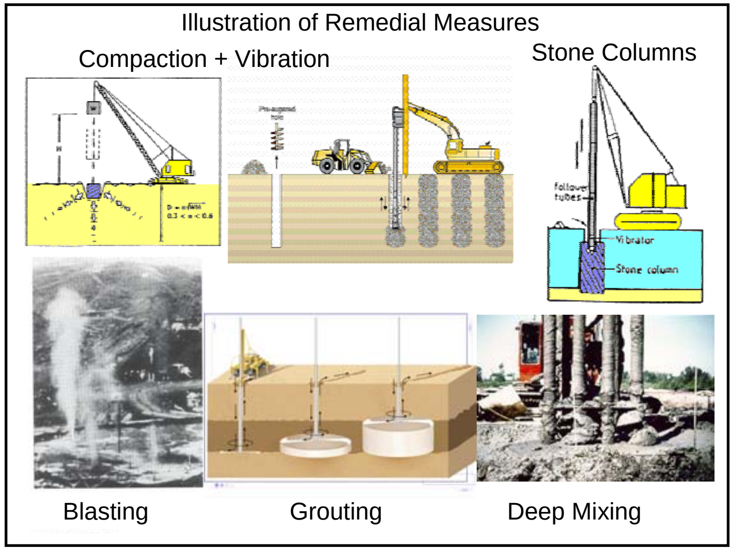


Illustration of Remedial Measures

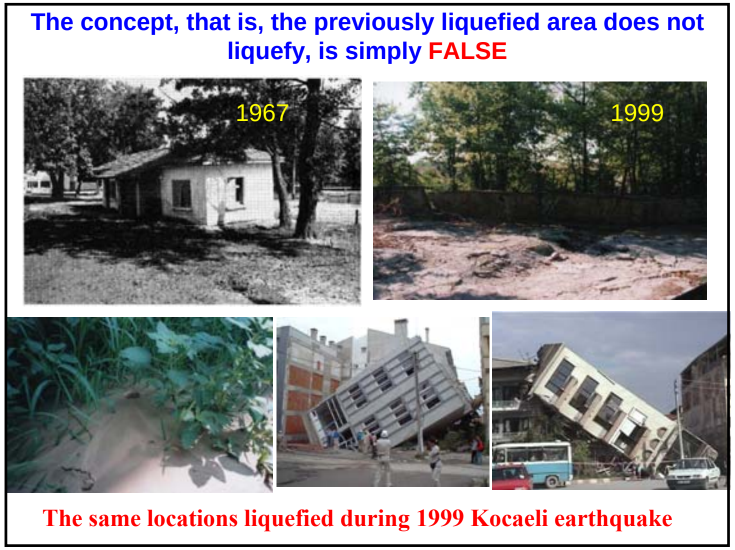
Compaction + Vibration

Stone Columns

Blasting

Grouting

Deep Mixing



The concept, that is, the previously liquefied area does not liquefy, is simply FALSE

The same locations liquefied during 1999 Kocaeli earthquake

Recent Great Earthquakes in the World and Some Lessons

, Sumatra 2005

Ömer AYDAN

Tokai University

JSCE-EEC

EWOB, Japan

Kashmir, 2005

Nias, 2005

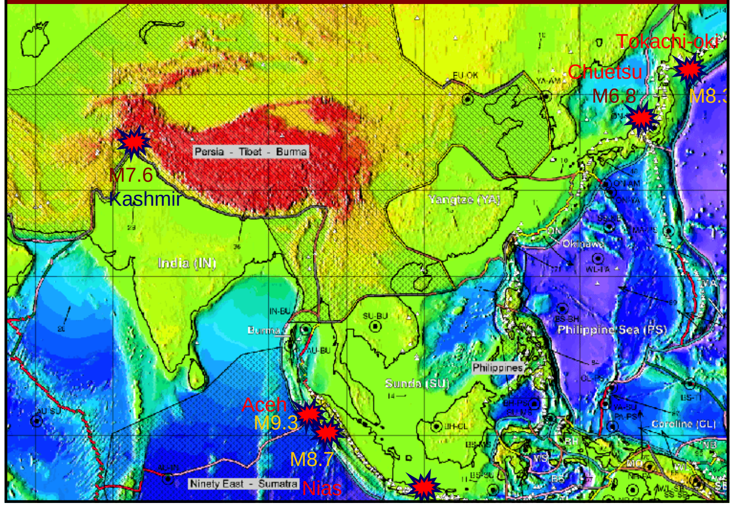
Tokachi-Oki, 2003

Chuetsu-Niigata, 2004

CONTENT

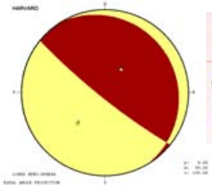
1) Earthquakes & Locations (Aceh, Nias, Chuetsu, Tokachi, Kashmir)
2) Characteristics of Earthquakes (Mecanism, seismic gap etc.)
3) Strong Motions (directivity, magnitude,footwall, hangingwall)
4) Tsunami (Aceh, Nias, Tokachi)
5) Liquefaction and its effects (Nias, Chuetsu, Tokachi, Aceh)
6) Causes of collapse of RC Buildings
7) Slopes instability and effects on structures (Kashmir, Chuetsu)
8) Permanent deformation and its effect on tunnels, bridges and viaducts (Kashmir-Nias-Chuetsu)
9) Effect of long-period waves

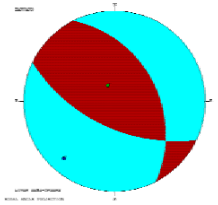
LOCATIONS



Focal Mechanism

Thrust type faulting

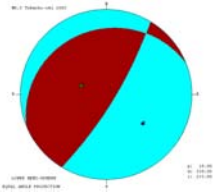


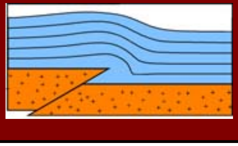


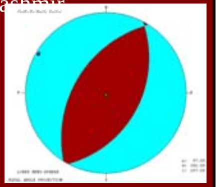
2004 Aceh-Aceh, 2005

2005 Kashmir-Kashmir

Blind thrust type faulting – active folding

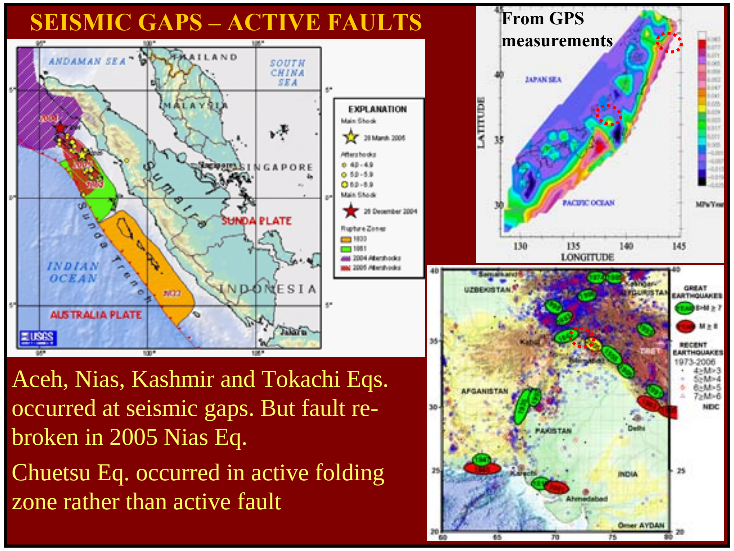






2003 TOKACHI

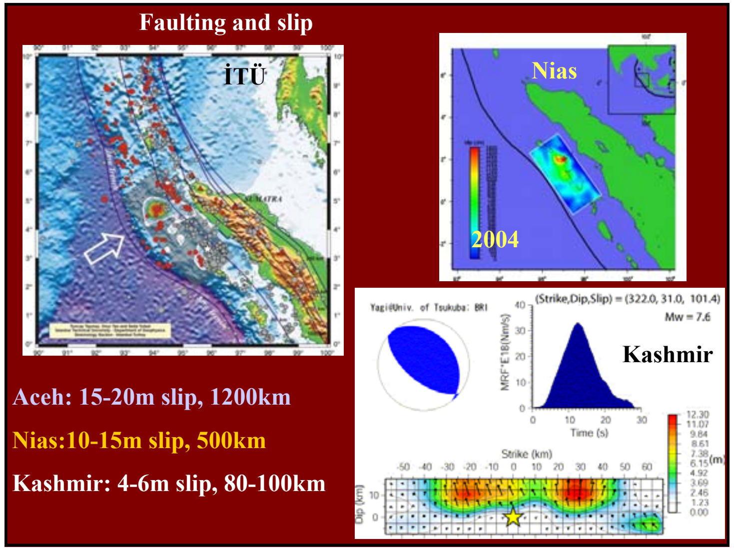
2004 Chuetsu-Chuetsu



SEISMIC GAPS – ACTIVE FAULTS

Aceh, Nias, Kashmir and Tokachi Eqs. occurred at seismic gaps. But fault re-broken in 2005 Nias Eq.

Chuetsu Eq. occurred in active folding zone rather than active fault

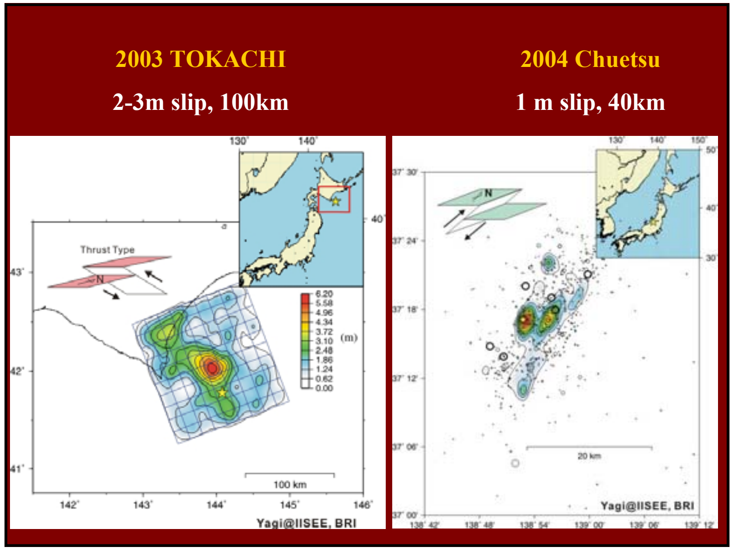


Faulting and slip

Aceh: 15-20m slip, 1200km

Nias:10-15m slip, 500km

Kashmir: 4-6m slip, 80-100km

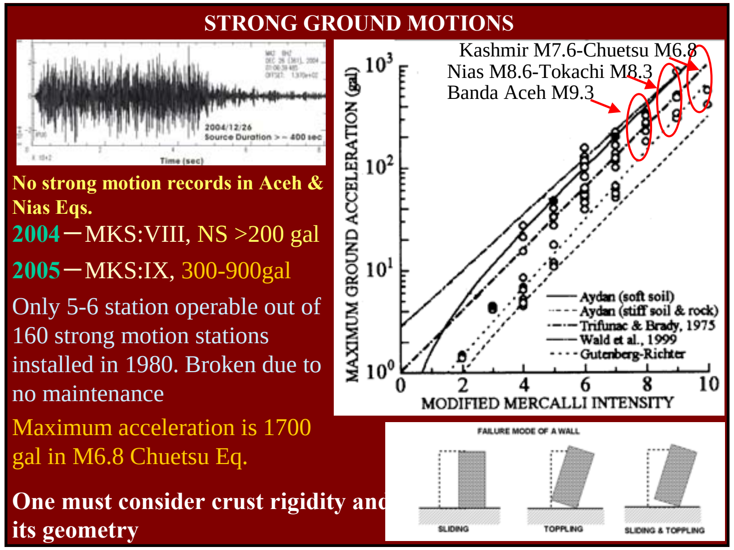


2003 TOKACHI

2-3m slip, 100km

2004 Chuetsu

1 m slip, 40km



STRONG GROUND MOTIONS

No strong motion records in Aceh & Nias Eqs.

2004ー MKS:VIII, NS >200 gal

2005ー MKS:IX, 300-900gal

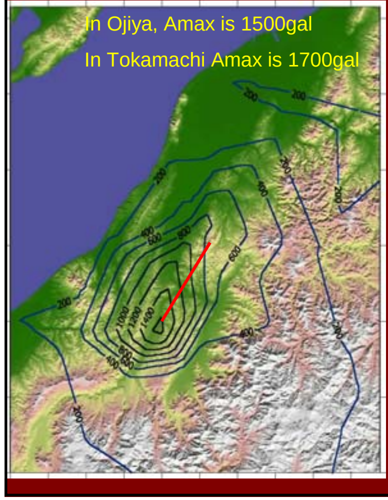
Only 5-6 station operable out of 160 strong motion stations installed in 1980. Broken due to no maintenance

Maximum acceleration is 1700 gal in M6.8 Chuetsu Eq.

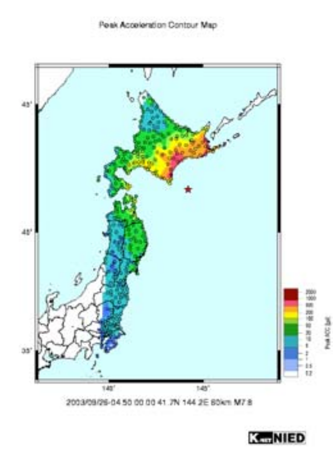
One must consider crust rigidity and its geometry

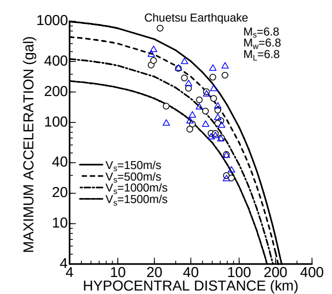
2004 Chuetsu Eq.

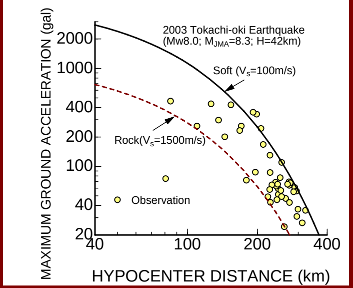
2003 Tokachi Eq.

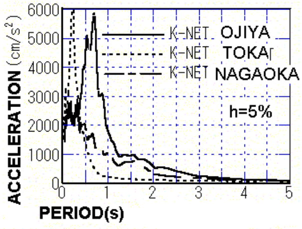

In Ojiya, Amax is 1500gal

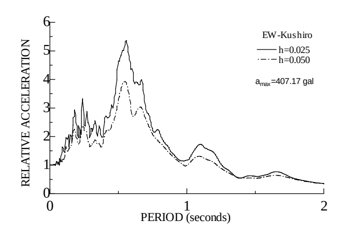
In Tokamachi Amax is 1700gal



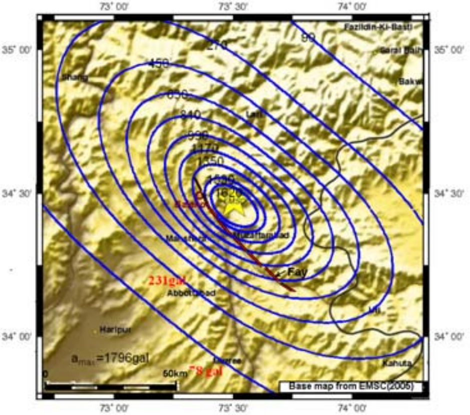








Kashmir Eq.



$$a_{\max} = F(V_s) * G(R,\theta) * H(M)$$

Base acceleration is 360-600 gals

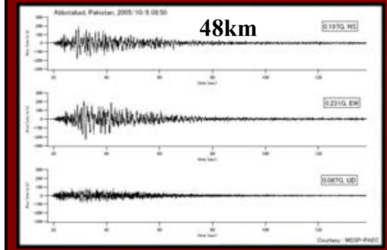
Acceleration is always greater in hangingwall block

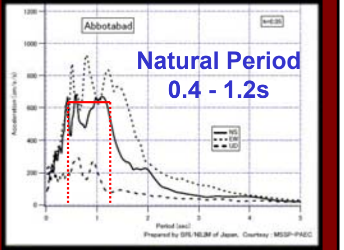
Amax > 1280 gals

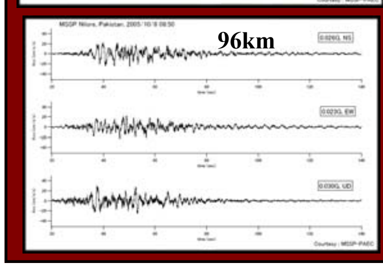
Vmax > 290 kines

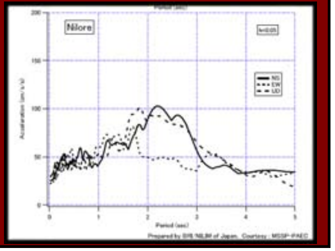
Dmax > 500cm

Kashmir SMR

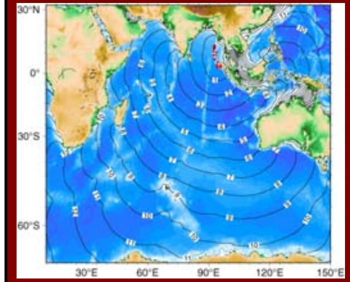

48km

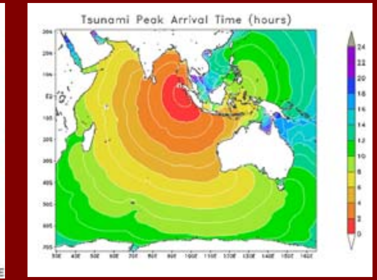

Natural Period 0.4 - 1.2s


96km



2004 Aceh **TSUNAMI** **2005 NİAS**

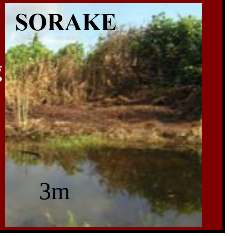




LEUPUNG

20-50m

Tsunami height differs depending upon seabed topography and depth



SORAKE

3m

Aceh earthquake is characterized by Tsunami rather than shaking

West coast 20m

North coast 10m

Inundation height 50m

First wave after 30 minutes

Effects of Tsunami on structures

- slamming
- dragging
- uplift
- pressure
- erosion

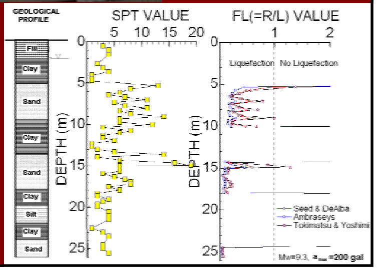
BANDA ACEH

2003 Tokachi Earthquake

STRUCTURAL DAMAGE

LIQUEFACTION & LATERAL SPREADING

BANDA
ACEH

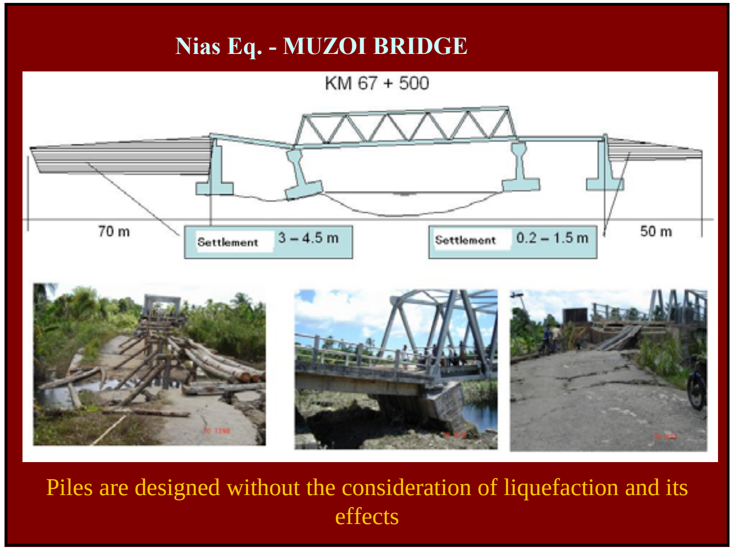


LIQUEFACTION INDUCED BY SHAKING AND TSUNAMI

Nias Eq. is characterized by liquefaction and its effects on structures

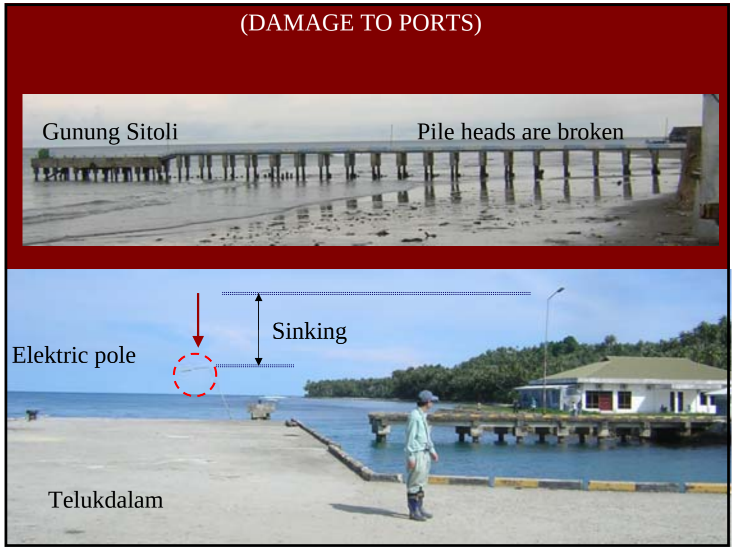
Building damaged by lateral spreading in Gunung Sitoli

(no tie-beams)



Nias Eq. - MUZOI BRIDGE

Piles are designed without the consideration of liquefaction and its effects



(DAMAGE TO PORTS)

2004 Chuetsu Earthquake, Liquefaction and lateral spreading

Lateral spreading, uplifting, sinking due to liquefaction

2003 Tokachi Earthquake

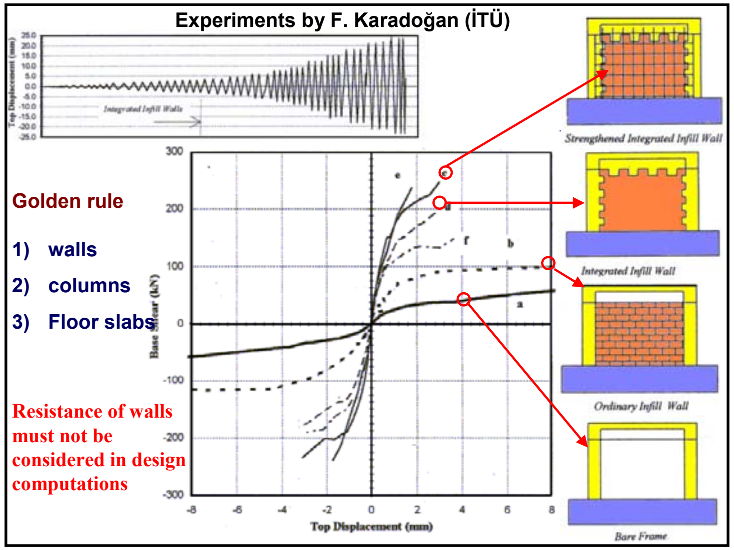
RC Building – Total Collapse – Weak Floor Phenomenon

Weak-floor
Lateral spreading

Poor construction and workmanship

2004 Aceh Earthquake

2005 Kashmir Earthquake

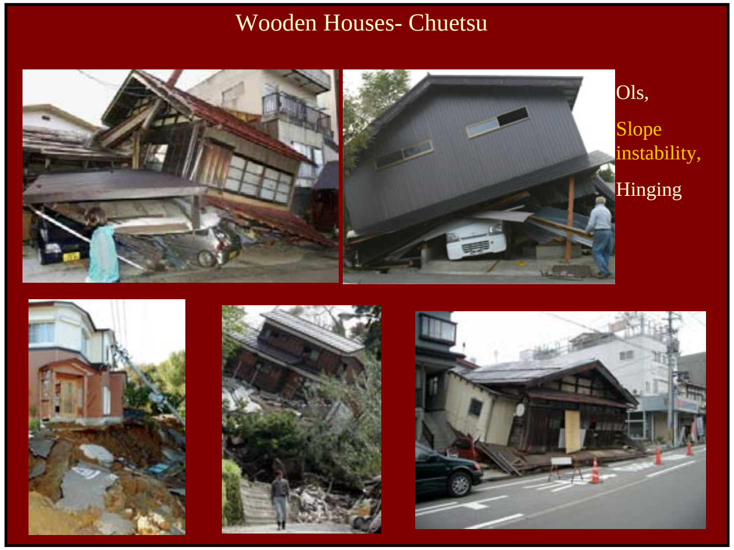


Experiments by F. Karadoğan (İTÜ)

Golden rule

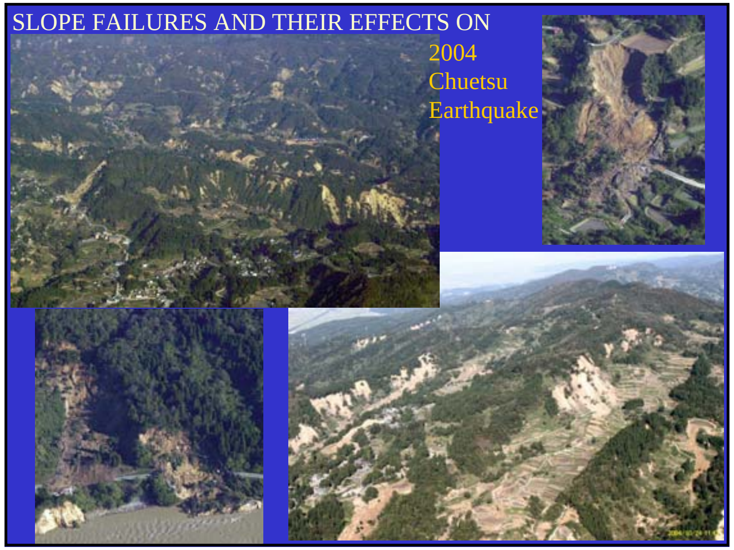
1) walls
2) columns
3) Floor slabs

Resistance of walls must not be considered in design computations



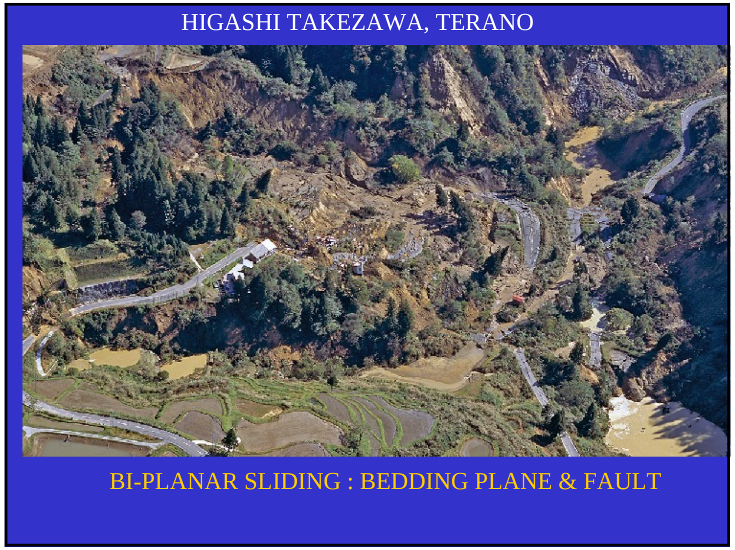
Wooden Houses- Chuetsu

Ols,
Slope instability,
Hinging



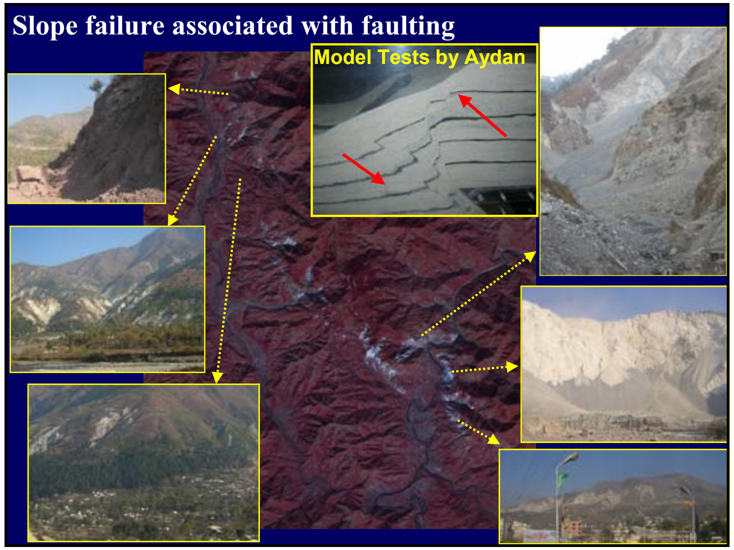
SLOPE FAILURES AND THEIR EFFECTS ON

2004
Chuetsu
Earthquake



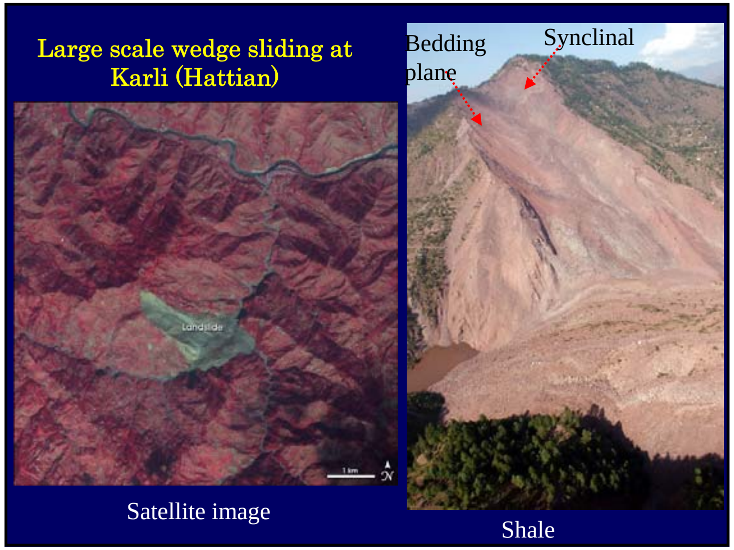
HIGASHI TAKEZAWA, TERANO

BI-PLANAR SLIDING : BEDDING PLANE & FAULT



Slope failure associated with faulting

Model Tests by Aydan



Large scale wedge sliding at Karli (Hattian)

Satellite image

Shale

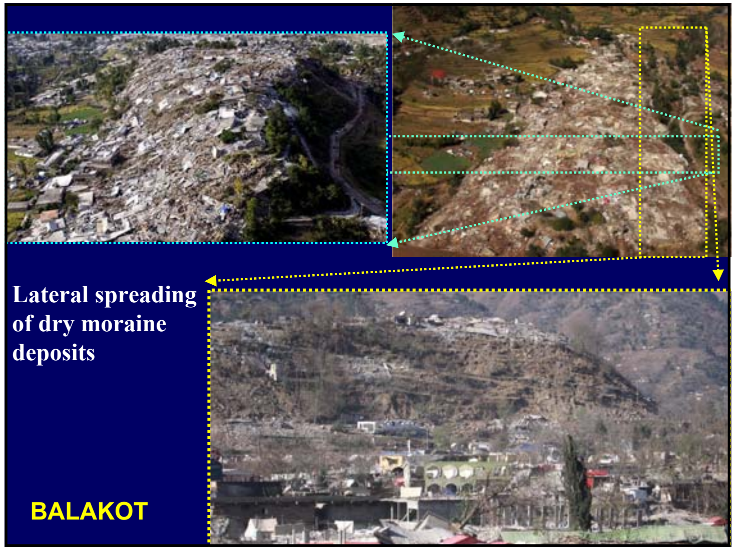
MUZAFFARABAD

NO TIE-BEAMS & Weak column-beam connection

HEAVY DAMAGE NEARBY SLOPE CREST

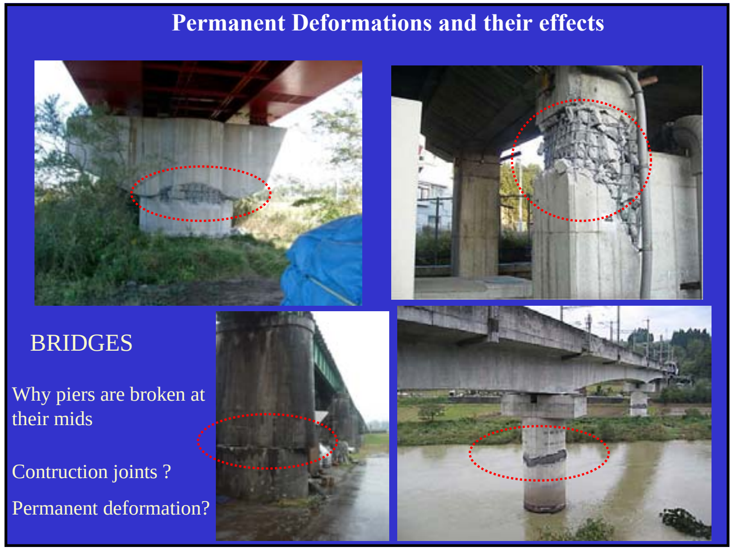
Amplication nearby slope crest

MUZAFFARABAD



Lateral spreading of dry moraine deposits

BALAKOT



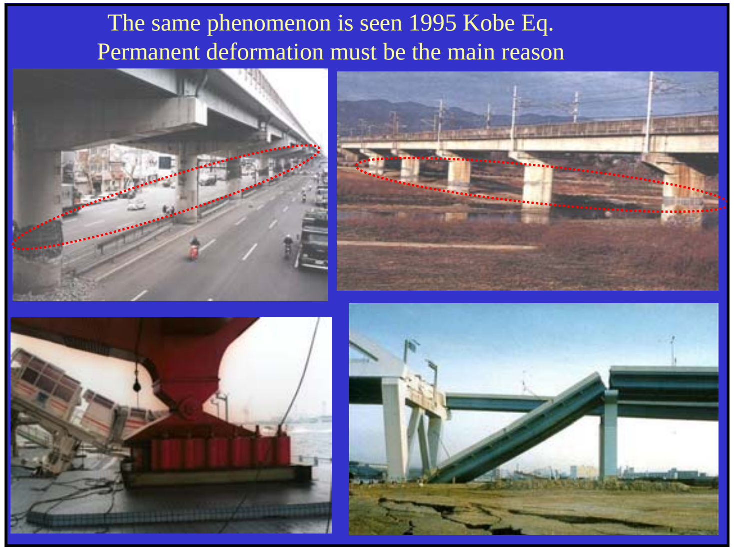
Permanent Deformations and their effects

BRIDGES

Why piers are broken at their mids

Contruction joints ?

Permanent deformation?



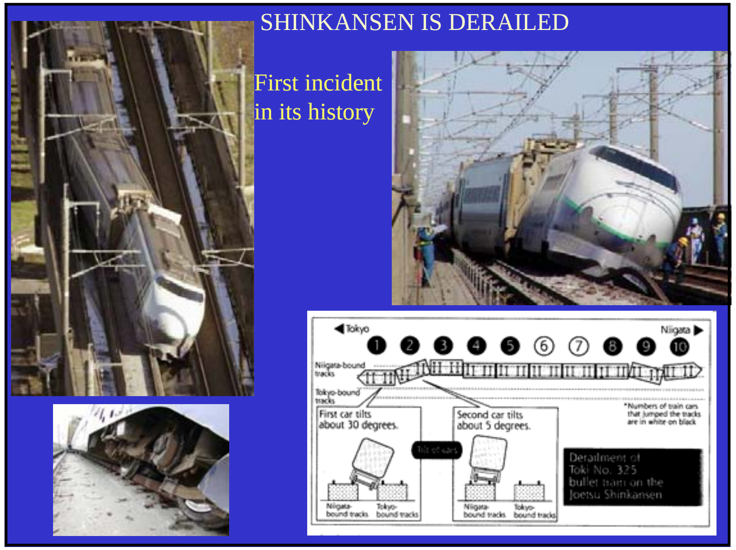
The same phenomenon is seen 1995 Kobe Eq.
Permanent deformation must be the main reason

TUNNELS

Shinkansen Tunnels

Lining are broken

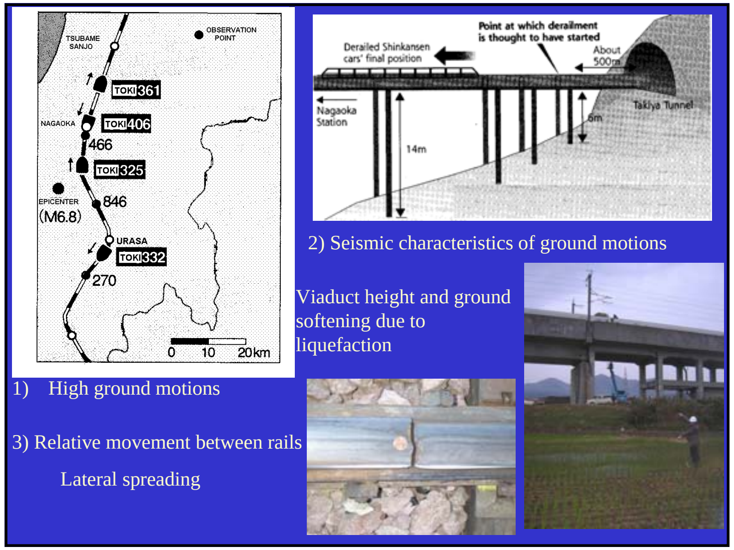
Man-made structures are broken



SHINKANSEN IS DERAILED

First incident in its history

One of reasons may be liquefaction induced lateral spreading



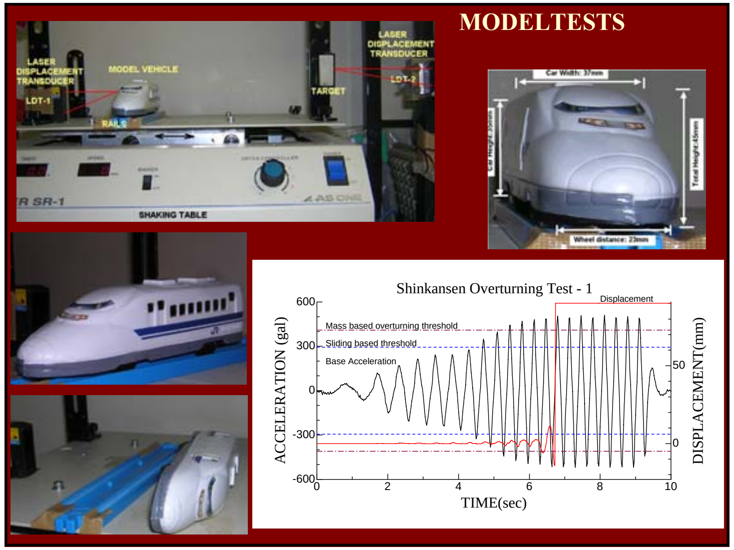
1) High ground motions

2) Seismic characteristics of ground motions

Viaduct height and ground softening due to liquefaction

3) Relative movement between rails

Lateral spreading



MODELTESTS

Tokachi Earthquake

Marimo Express

SEISMIC EVALUATION AND REHABILITATION OF VULNERABLE RC BUILDINGS
- EXPERIENCES AND LESSONS IN JAPAN -

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Key Words: seismic evaluation, seismic rehabilitation, RC buildings

INTRODUCTION

Japan is located in an earthquake-prone region and has experienced numbers of damaging earthquakes. During the last several decades, various efforts have been made on the development of seismic design methodologies, evaluation of existing buildings, upgrading vulnerable buildings. In this paper, background experiences on damaging earthquakes, current efforts and countermeasures are briefly overviewed focusing on RC buildings in Japan, and key issues on seismic evaluation and related technical aspects which may help future development of seismic upgrading of buildings in Indonesia are discussed.

BRIEF HISTORY OF DAMAGING EARTHQUAKES AND SEISMIC EVALUATION IN JAPAN

Since 1920's, a large number of RC buildings have been designed and constructed in Japan according to the seismic code (see Table 1). Damage to buildings due to past earthquakes such as 1968 Tokachi-oki earthquake or 1978 Miyagiken-oki earthquake, however, revealed that some of the existing RC buildings may not have sufficient seismic capacity and may sustain serious damage due to severe earthquakes. The most important lessons learned from the observed damage was that the ultimate lateral resistance of existing building might be different even if they had been designed according to the same seismic code, i.e., some buildings may have lateral resistance significantly exceeding code-specified strength while others may have insufficient resistance and ductility against strong shakings. It was, therefore, an upsurge among earthquake engineers to develop the technique to find out and rehabilitate vulnerable buildings to mitigate damage against future earthquakes.

After the 1968 Tokachi-oki earthquake, comprehensive research projects to revise the seismic code and to develop the new seismic design methodology actively started. At the same time, various techniques to estimate seismic capacity of existing RC buildings have been proposed. In 1977, the

Table 1 Damage statistics due to past earthquakes in Japan

	Damaging earthquakes and related issues	Magnitude	Fatalities	Damaged buildings	
				Heavy	Moderate
1891	Nobi	8.4	7273	142177	-
1923	Kwanto	7.9	99331	128266	126233
1924	***Urban Building Law (applied to buildings in urban cities)***				
1944	Tohnankai	8.0	998	26130	46950
1946	Nankai	8.1	1330	11591	23487
1948	Fukui	7.3	3895	35420	11449
1950	***Building Standard Law (applied to buildings throughout the country)***				
1964	Niigata	7.7	26	2134	6293
1968	Tokachi-oki	7.9	50	928	4969
1971	***Revision of Seismic Code***				
1977	***Seismic Evaluation Standard and Rehabilitation Guidelines (RC)***				
1978	Miyagiken-oki	7.4	28	1383	6190
1981	***Revision of Seismic Code***				
1990	***Revision of Standard and Guidelines (RC)***				
1995	Hyogoken-Nambu (Kobe)	7.3	6432	105000	144000
	Law to promote Seismic Evaluations and Rehabilitations				
2001	***Revision of Standard and Guidelines (RC)***				
2004	Niigata-ken-chuetsu	6.8	65	3175	13792

unified standard and guidelines for seismic evaluation and rehabilitation of existing RC buildings (JBDPA a, b) were developed by the special committee at the Japan Building Disaster Prevention Association under the sponsorship of the Ministry of Construction, Japanese Government, and have been applied to existing buildings. Their applications had been, however, localized in Tokyo Metropolitan Area including Chiba and Kanagawa prefectures, or in Shizuoka prefecture where a large-scale earthquake named “Hypothetical Tokai Earthquake” is predicted to occur in the near future from the seismological point of view.

The 1995 Hyogoken-nambu (Kobe) earthquake caused devastating damage to urban centers and triggered a new direction in seismic evaluation and rehabilitation of existing vulnerable buildings in Japan. Fig. 1 shows the damage statistics of RC school buildings due to the Kobe earthquake (Nakano 2004, after AIJ 1997). In the last 4 decades, the Japanese seismic design code was revised in 1971 and 1981 (see Table 1). As can be found in the figure, the damage rate is highly dependent on the code generation, and those designed in accordance with the pre-1981 code had more serious damage. The widespread damage to older buildings designed to meet the code criteria of the time of their construction revealed the urgency of implementing rehabilitation of seismically vulnerable buildings.

Since the catastrophic event of Kobe earthquake, various integrated efforts have been directed by the Japanese Government and engineering professionals toward upgrading seismic performance of vulnerable buildings and implementing learned and re-learned lessons for earthquake loss mitigation. Several new laws such as *Special Measures Law on Earthquake Disaster Prevention* and *Law to Promote Seismic Rehabilitation* promulgated soon after the event have undoubtedly served as fundamentals for nationwide programs for seismic rehabilitation of vulnerable buildings. It should be noted, however, that it was almost 20 years since the Seismic Evaluation Standard was first developed in 1977.

BASIC CONCEPT OF SEISMIC EVALUATION IN JAPAN

Basic Concept of Evaluation

Since the first development of the Standard and the Guidelines in 1977, they have been revised twice in 1990 and in 2001 but the basic concept to evaluate seismic capacities of buildings has been unchanged. In the Standard, the seismic capacity of a structure is expressed by the *Is*-index at each story level and each direction, defined primarily in the following function form.

$$Is = f\,(C, F, S_D, T) \qquad (1)$$

where, *Is*-index is seismic capacity index; C- and *F*-index are lateral resistance index and ductility index, respectively; S_D- and *T*-index are modification factors to allow for the negative effects on seismic capacity due to the structural irregularity and deterioration after construction, respectively. Detailed descriptions on the seismic evaluation procedure can be found in Appendix in this paper.

As is well accepted in the earthquake engineering field, the ductility and strength is essential factors to design a structure. This is all the same in evaluating the seismic capacity of existing buildings and even in analysis. As summarized in Table 2, the difference among them is "what is given ?" and "what will be obtained ?".

This Standard has been widely applied to the existing building in Japan, especially after the nationwide projects on seismic evaluation and rehabilitation started following the 1995 Kobe earthquake. Fig. 2 shows the histogram of *Is*-index of existing RC buildings in Japan, where more than 1,600 buildings are evaluated. This graph provides valuable information about seismic capacity

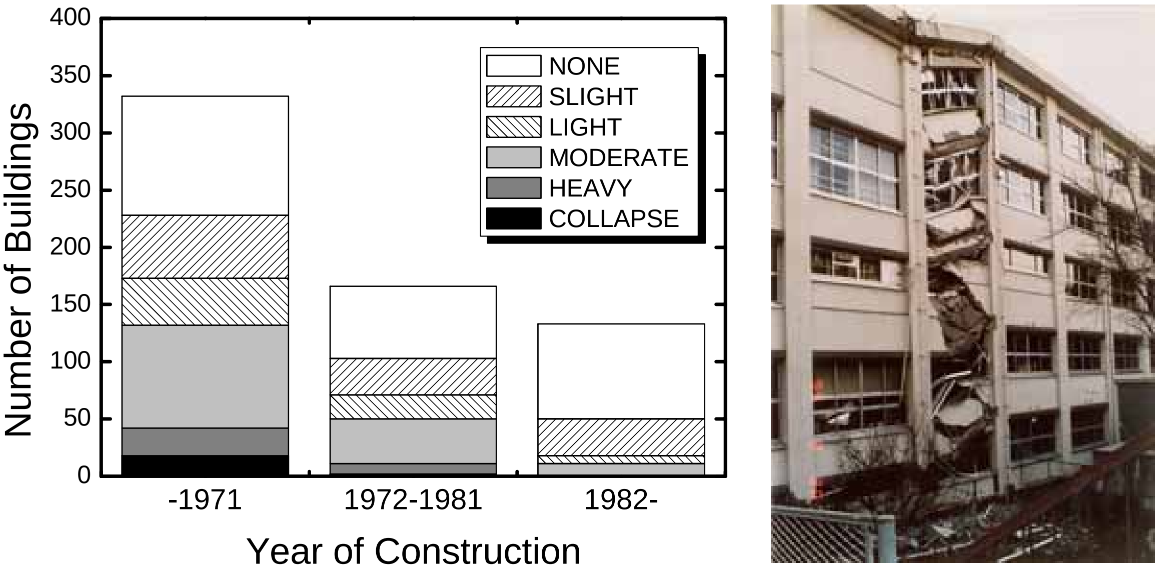


Fig. 1 Damage statistics of RC schools after 1995 Kobe earthquake (Nakano 2004, after AIJ 1997)

Table 2 Relationship of analysis, design and evaluation

	response analysis	seismic design	seismic evaluation
earthquake motion (Max acceleration)	given	given	to be obtained
resistance (yield strength)	given	to be obtained	given
displacement (ductility)	to be obtained	given	given

of RC buildings before damaging earthquake and further serves as the fundamental data for damage estimation to future earthquakes, criteria setting to identify candidate buildings to be seismically rehabilitated, investigations of rehabilitation effects on damage mitigation (Okada and Nakano 1988).

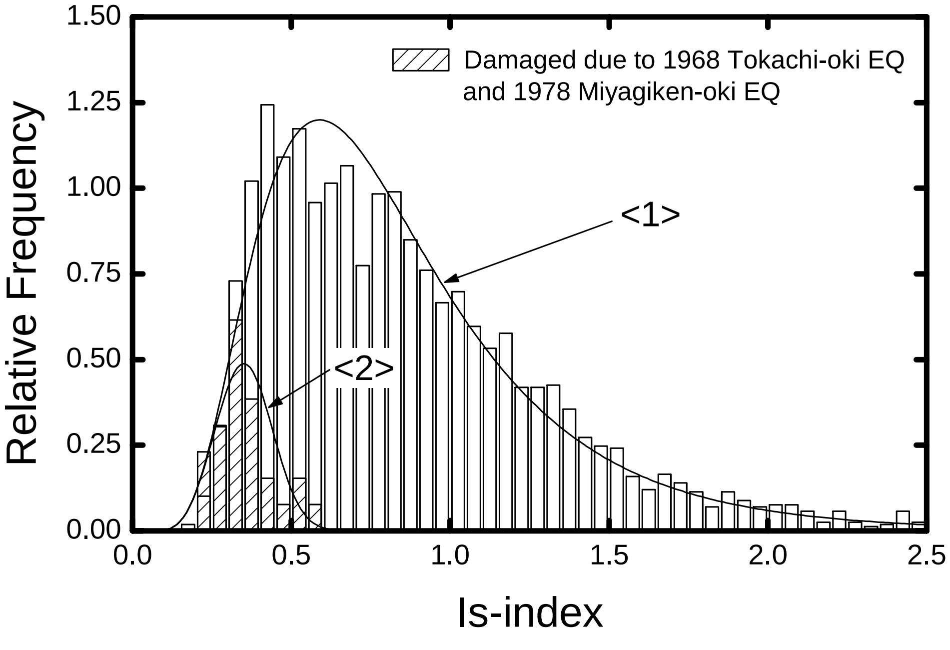
Criteria to Identify Safe Buildings

To evaluate the structural safety against future earthquakes, it is also essential to determine the required seismic capacity, i.e., criteria to identify buildings for seismic rehabilitation. In the Guidelines (JBDPA b), a building with *Is*-index larger than the required seismic capacity index, *Iso*, as shown in Eq. (2) is judged "safe."

$$Is \geq Iso \qquad (2)$$
$$Iso = Es \times Z \times G \times U$$

In Eq. (2), *Es*-index is a basic seismic capacity required for the building concerned. *Z*-, *G*-, and *U*-index are factors to allow for the seismicity, ground condition, and importance of the building, respectively.

One possible way to determine the required seismic capacity is to compare the capacity between damaged and survived buildings in the past earthquakes. The hatched area in Fig. 2 shows the histogram of *Is*-Indices for moderately or severely damaged buildings due to 1968 Tokachi-oki earthquake or 1978 Miyagiken-oki earthquake. As can be found in the figure, no major damage was found in buildings with *Is*-index higher than 0.6 during these two earthquakes. Similar investigations were also made after the 1995 Kobe earthquake, and the basic required capacity index 0.6 is considered appropriate for the criteria to identify candidates for seismic rehabilitation.



NOTE: The histogram in white represents the distribution of *Is*-index of more than 1,600 RC buildings in Shizuoka prefecture before damaging earthquakes. The distribution can be approximated with a log-normal function shown with the curve <1>. The hatched area indicates damaged buildings due to two major earthquakes. As can be found in the figure, no major damage was found in buildings with *Is*-index higher than 0.6 during these two earthquakes. The curve <2> in the figure is obtained from a probabilistic study to numerically estimate the damage distribution.

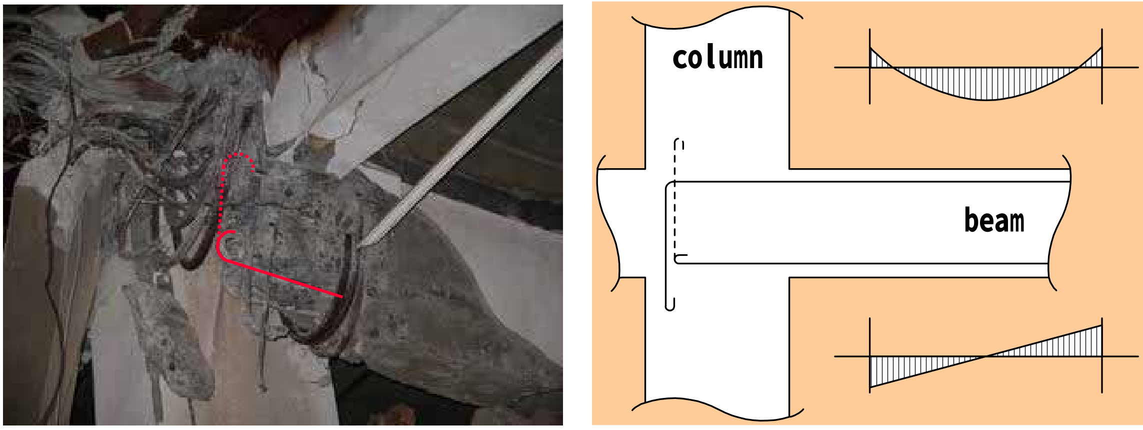
Fig. 2 Distribution of *Is*-index in Japan (Okada and Nakano 1988)

ESSENTIALS FOR SEISMIC EVALUATIONS

Weak Link Governing Structural Performance

Strength and ductility of structural members are the most essential factors for seismic evaluation of structures. Their flexural and shear strengths are usually of great significance in evaluating seismic capacity of RC buildings when either flexural or shear strength of members governs the structural behavior. This is especially so when the joints between members such as beam-column joints are rigidly connected, and damage is expected to occur primarily along structural members. It should be noted, however, that premature failure due to pull-out failure of beam rebars at beam-column joints and/or beam-column failures are often found after 2006 Central Java earthquake as well as other damaging earthquakes as shown in Photos 1 and 2. This damage is attributed to the improper design detailing of reinforcement placed in members, causing strength and ductility lower than potential member performance.

To properly estimate the structural performance and the seismic capacity of buildings in Indonesia, pull-out failures of rebars and beam-column joint failures as well as typical shear (and also flexural) failure in columns and walls should be taken into account in evaluating member strength and



Note: Some beam bottom reinforcing bars were improperly detailed and pulled out of the beam-column joints. They had 180-degree hooks in the ends but were straightly terminated in the joints without bent anchorage into the joint core concrete. Rigid beam-column joints properly confined with lateral reinforcement and beam reinforcement bent into the joint core to develop its full anchorage are most essential for RC structures to perform successfully during earthquakes.

Photo 1 Pull-out failure of beam rebars at joint during 2006 Central Java Earthquake

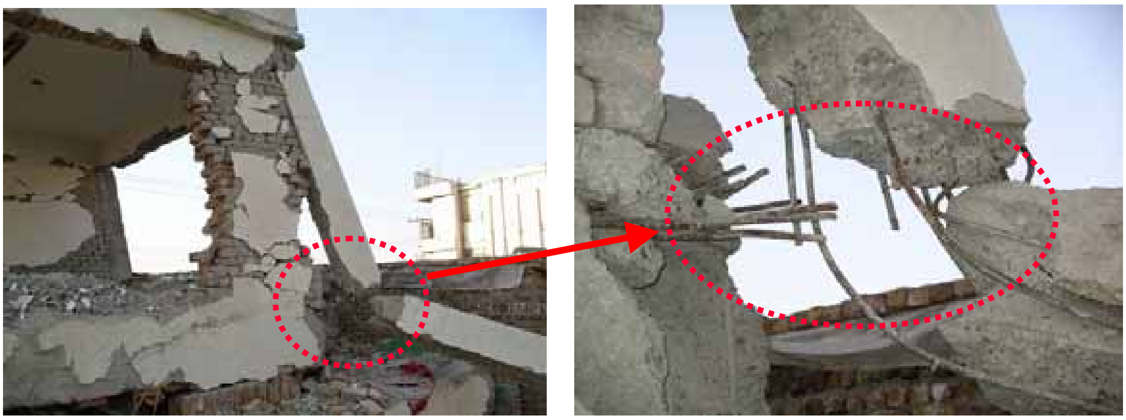


Photo 2 Collapsed 3 story building due to beam-column joint failure during 2005 Pakistan Earthquake

estimating the failure pattern of an entire structure. To identify the weak link is also of great importance to properly determine strategies (i.e., where and how to strengthen) for seismic rehabilitation of vulnerable buildings.

Highly sophisticated computer programs may not help much understand structural responses and predict failure sequences during strong shakings unless expected failure modes are properly considered in computations.

Contribution of Nonstructural Elements to Structural Performance

Nonstructural elements placed in RC frames, which are most typically masonry walls, are often neglected in the structural design. Past damaging earthquake, however, often revealed that they significantly affected structural responses due to column shortening, stiffer frames causing unexpected soft story in the adjacent story above and/or below, etc. as shown in Photos 3 and 4. Although the conservative strength may be obtained through neglecting effects of nonstructural elements, they may give adverse effects on structural performance and eventually cause brittle failures.

To evaluate the seismic capacity, effects of nonstructural elements on structural behavior should be properly taken into account.

1992 Erzincan EQ (Turkey) 2004 Chuetsu EQ (Japan) 1999 Chi-Chi EQ (Taiwan)

Photo 3 Contribution of nonstructural elements to column shortening and damage

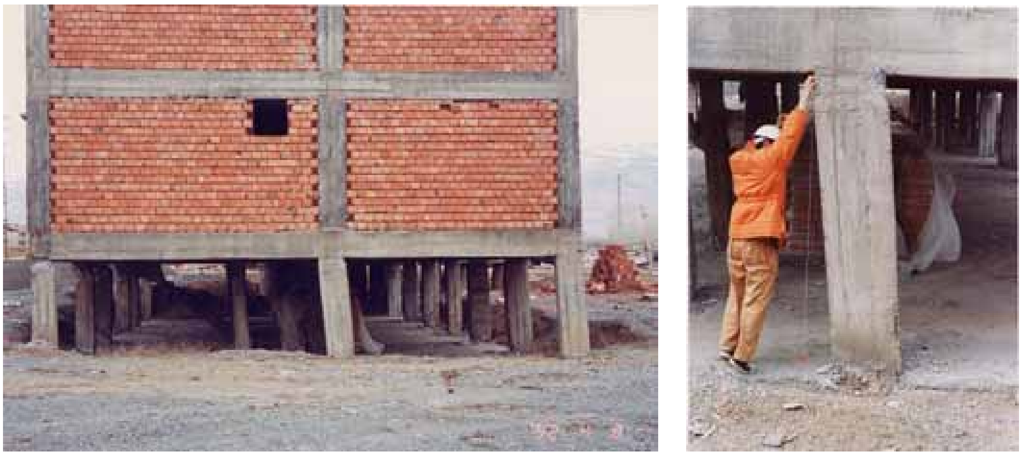


Photo 4 Contribution of nonstructural elements to soft first story (1992 Erzincan EQ)

Appropriate Structural Modeling

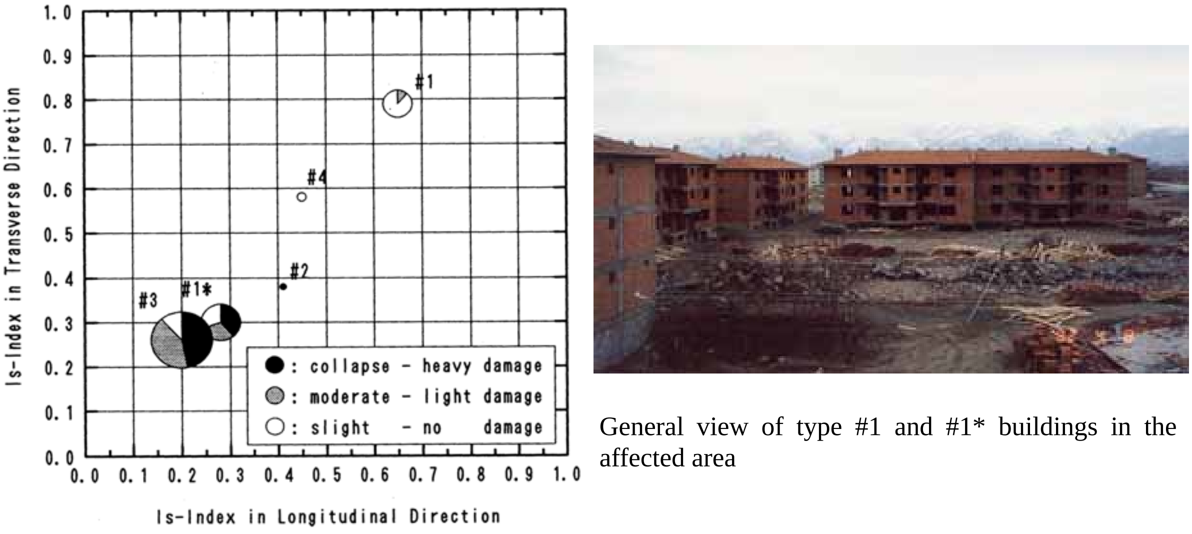
Existing structures are mathematically modeled in computing their responses. The results are therefore definitely dependent on the appropriateness of structural modeling. When the mathematical model describing a structure concerned does not represent the *real* structure, the calculated results would not be reliable enough to predict their behavior. The structural modeling for computation, therefore, would be a key factor to obtain right answers. This is exactly so even when a sophisticated computer programs are used to estimate the seismic behaviors of buildings.

Existing buildings are not often well balanced from the structural design point of view, and this may cause difficulties in their mathematical modeling to obtain right answers. The importance of rational structural modeling rather than high level computer codes (e.g., 3D or FEM etc.) should be highly focused and recognized by engineers for successful seismic evaluations.

Data Collection for Criteria Setting

The criteria to identify safe buildings, or the required capacity against future earthquakes expected at the site, should be determined through comparison between evaluation results and observed damage as well as numerical simulation results. As described earlier, the required capacity in Japan is made through intense studies on the relationship between *Is*-index and observed evidence in the past damaging earthquakes, together with statistical/probabilistic studies and nonlinear response analyses.

The Japanese Standard also has been applied to buildings outside Japan such as Mexico (after 1985 Mexico EQ), Turkey (after 1992 Erzincan EQ and 1999 Kocaeli EQ), Taiwan (after 1999 Chi-Chi EQ), Pakistan (after 2005 Kashmir EQ), etc. to investigate their seismic capacities and to identify major reasons of damage (Okada et al. 1988, Nakano and Kato 1994). Fig. 3 shows an application example after 1992 Erzincan earthquake in eastern Turkey. In this study, the correlation of seismic performance and *Is*-index of 5 standard structural designs (types #1, #1*, #2, #3, and #4) is investigated. In the affected area, approximately 100 buildings were designed and constructed according to either design type #1, #1*, or #3. The size of each circle in the figure corresponds to the number of buildings constructed according to an identical standard design type and the shaded portion shows the ratio of 3 structural damage categories shown in the legend. As can be found in the figure, the damage ratio increases according to decrease in *Is*-index, and the index can be a good estimator to identify vulnerable buildings in the affected area in Turkey.



General view of type #1 and #1* buildings in the affected area

Fig. 3 Application example of Japanese Seismic Evaluation Standard after 1992 Erzincan Earthquake in Turkey (Nakano and Kato 1994)

Statistical investigations utilizing seismic capacities of both damaged and survived buildings, as described above, are effective to find rational criteria. Note that the data on buildings that survived an event or those that have not yet experienced damaging earthquakes should also be collected since they are valuable for criteria setting through comparison with those on damaged buildings.

Review of Evaluation Results

To predict seismic performance that is most likely to be achieved under strong ground shaking is the first priority for seismic evaluations. This would lead the building to successful rehabilitation if it needs redesign for upgrading seismic performance. To this end, a review committee consisting of professionals on building engineering such as university professors, practitioners, building officials etc. is generally set up in each local district in Japan. In the committee, structural modeling, calculations results, and rehabilitation proposals are reviewed from the effectiveness and economical engineering practice point of view based on sound engineering and scientific principles and knowledge.

This system helps engineers find rational solutions for seismic evaluation and rehabilitation of buildings in Japan.

Education Programs of Engineers

The main objective of seismic evaluation is to properly estimate structural behaviors. It should be, however, noted that the seismic evaluation as well as redesign for rehabilitation is often more difficult than designing new constructions. Proper estimations can be made through knowledge and experiences on structural mechanics and dynamics, structural design and practice, and lessons learned from earthquake damage. Transfer of engineering knowledge and experiences from well-experienced professionals is of great importance for continued activities to evaluate seismic capacity of existing buildings and to upgrade seismic performance of vulnerable buildings since a safer city can bot be built in a day.

CONCLUSIONS

Seismic evaluations are undoubtedly most important for a better understanding of seismic capacities of existing buildings and predicting their responses. Rational strategies to upgrade seismically vulnerable building can be identified only with right estimations of structural performances. The estimated results should be, of course, consistent with the weak link and the consequent failure mechanism observed in the past damaging earthquakes. For this purpose, the development of evaluation procedure that can describe primary behaviors governing the responses of entire structure is most essential.

Criteria setting to identify safe buildings is another task when a seismic evaluation is made on a building. This can be achieved through a combination of comparison between evaluation results and observed damage, numerical simulations, and earthquake hazard.

To complete a system for seismic evaluation is a hard task which may need persistent and patient efforts, but it can not be achieved without rational observation of evidence. The authors do hope that engineers in Indonesia could develop and implement seismic evaluation procedure through sharing information and knowledge obtained from earthquake damage in both countries.

APPENDIX: BASIC CONCEPT OF JAPANESE STANDARD FOR SEISMIC EVALUATION OF EXISTING RC BUILDINGS

The Standard for Seismic Evaluation (JBDPA 1990a, 2001a), designed primarily for pre-damaged existing RC buildings in Japan, defines the following structural seismic capacity index *Is* at each story level in each principal direction of a building.

$$Is = Eo \text{ x } S_D \text{ x } T \qquad \text{(A-1)}$$

where, *Eo* : basic structural seismic capacity index, calculated by the product of Strength Index (*C*), Ductility Index (*F*), and Story Index (ϕ) at each story and each direction when a story or a building reaches the ultimate limit state due to lateral force ($Eo = \phi \text{ x } C \text{ x } F$)

C : index of story lateral strength expressed in terms of story shear coefficient

F : index of story ductility, calculated from the ultimate deformation capacity normalized by the story drift of 1/250 when a typical-sized column is assumed to fail in shear. *F* is dependent on the failure mode of a structural member and its sectional properties such as bar arrangement, member's geometric size etc. *F* is assumed to be in the range of 1.0 to 3.2 for ductile columns, 1.0 to 1.27 for brittle columns, and 0.8 for extremely brittle short columns; 1.0 to 2.0 for ductile walls and 1.0 for brittle walls.

ϕ : index of story shear distribution during earthquake, estimated by the inverse of design story shear coefficient distribution normalized by the base shear coefficient. $\phi = (n+1)/(n+\text{i})$ is basically employed for the *i*-th story of an *n* story building

S_D : reduction factor to modify *Eo* index due to stiffness discontinuity along stories, eccentric distribution of stiffness in plan, irregularity and/or complexity of structural configuration, basically ranging from 0.4 to 1.0

T : reduction factor to allow for time-dependent deterioration grade, ranging from 0.5 to 1.0

A required seismic capacity index *Iso*, which is compared with *Is*-index to identify structural safety against an earthquake, is defined as follows.

$$Iso = Es \text{ x } Z \text{ x } G \text{ x } U \qquad \text{(A-2)}$$

where, *Es* : basic structural seismic capacity index required for the building concerned. Considering past structural damage due to severe earthquakes in Japan, the standard value of *Es* is set 0.6.

Z : factor allowing for the seismicity

G : factor allowing for the soil condition

U : usage factor or importance factor of a building

Typical *Iso* index is 0.6 considering *Es* = 0.6 and other factors of 1.0. It should be noted that C_T x S_D defined in Eq. (A-3) is required to equal or exceed 0.3 *Z* x *G* x *U* in the Standard to avoid fatal damage and/or unfavorable residual deformation due to a large response of structures during major earthquakes.

$$C_T \text{ x } S_D = \phi \text{ x } C \text{ x } S_D \qquad \text{(A-3)}$$

Seismic rehabilitation of existing buildings is basically carried out in the following procedure.

(1) Seismic evaluation of the structure concerned (*Is* and C_T x S_D)
(2) Determination of required seismic capacity (*Iso*)
(3) Comparison of *Is* with *Iso* and of C_T x S_D with 0.3 *Z* x *G* x *U*

* If $Is < Iso$ or $C_T \text{ x } S_D < 0.3\ Z \text{ x } G \text{ x } U$ and therefore rehabilitation is required, the following actions (4) through (6) are needed.

(4) Selection of rehabilitation scheme(s)
(5) Design of connection details
(6) Reevaluation of the rehabilitated building to ensure the capacity of redesigned building equals or exceeds the required criteria

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Paper Number:1426

DAMAGE IN NIAS ISLAND CAUSED BY THE M8.7 OFF-SHORE SUMATRA EARTHQUAKE, MARCH 28, 2005

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SUMMARY

A very large earthquake with a magnitude of 8.7 occurred nearby Nias Island of Indonesia on March 28, 2005. Strong ground motions induced heaviy casualities and damages to structures. The earthquake induced widespread liquefaction and lateral spreading. RC buildings having 2 or more stories were collapsed in the pancake mode or heavily damaged. The main causes of the damage of the structures in this earthquake can be broadly classified as follows: a) Soil liquefaction and lack of the bearing capacity of ground in the coastal areas and nearby river banks, b) Fragile structural walls and lack of lateral stiffness. c) Poor concrete quality and workmanship d) Plastic hinge development at the beam-column joints, e) Lack of shear reinforcement and confinement, f) Soft story, g) Ground motion characteristics. Lateral ground movements, settlement and the effects of ground liquefaction such as sandboils were observed at the sandy ground along sea shore and riverbanks. Many buildings collapsed, tilted and settled, also bridges and port facilities were damaged along the coastal area and reclaimed ground in Gunung Sitoli, Telukdalam and other lowland area. The lateral spreading of ground nearby bridge abutments were almost associated with liquefaction of sandy soil layer.

1. INTRODUCTION

The Sumatra Earthquake of December 26, 2004 caused the most disastrous tsunami in Indian Ocean and severe disaster to the countries around the Indian Ocean, especially in Indonesia. Three months after the earthquake, another large earthquake with a magnitude 8.7 occurred on March 28, 2005 nearby Nias Island at the west coast area of Sumatra 500km away from the epicenter of the 2004 earthquake. Severe damage was caused by strong ground motion in especially Nias Island. For these disasters, Japanese organizations in cooperation with some Indonesian organizations conducted support activities for the recovery and reconstruction of the affected areas, such as making recommendations and instructions for geotechnical investigations and the practical utilization of its results for temporary repair and rehabilitation of infrastructures and buildings [Support Team of JSCE, 2005], [Miwa et al., 2006a] and educational activities on disaster prevention [Hamada et al., 2005], [Tsukazawa et al.,

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2005], [Kitajima et Al., 2006] besides the reconnaissance surveys of earthquake affected areas. In this article, the characteristics of M8.7 offshore Sumatra earthquake, March 28, 2005 and induced damages in Nias island obtained during these activities e.g. [Aydan et al. 2005], [Miwa et al. 2006a] and additional studies are described.

2. THE CHARACTERISTICS OF THE EARTHQUAKE AND OUTLINE OF THE RECONNAISANCE

Table 1 shows main characteristics of the earthquake inferred by USGS [USGS, 2005] and Harvard University [Harvard, 2005]. USGS estimated that magnitude (Mw) was 8.7 and hypocenter was just beneath Banyak Islands to the north of Nias Island. The hypocenter estimated by Harvard was further south and nearby Nias Island. Rapture and slip characteristics estimated by Yagi [Yagi, 2005] and Yamanaka [Yamanaka, 2005] are given in Table 2. Figure 1 shows the rupture area estimated by Yagi [Yagi, 2005]. The length and width of rupture area were inferred to be about 470km and about 100km, respectively and slip was about 10m, The earthquake is a low-angle reverse fault type mega earthquake in inter-plate subduction zones. Severe damage occurred in Nias island because the high energy release just beneath the island.

Table 1: Main characteristics of Earthquake

Institute	Mw	Latitude (N)	Longitude (E)	Depth (km)
USGS	8.7	2.076°	97.013°	30.0
Harvard	8.6	1.64°	96.98°	24.9

Table 2: Rupture and Slip Characteristics of the earthquake fault

	Yagi (2005)	Yamanaka (2005)
Strike, Dip, rake	(329,14,115)	(320,12,104)
Moment Tensor Scale	1.6×10^{22} Nm	1.3×10^{22} Nm
Rupture Duration Time	150s	120s
Depth	28 km	27 km
Rupture Area	about 150×470 km	about 120×250 km
Slip	about 10 m	about 12 m

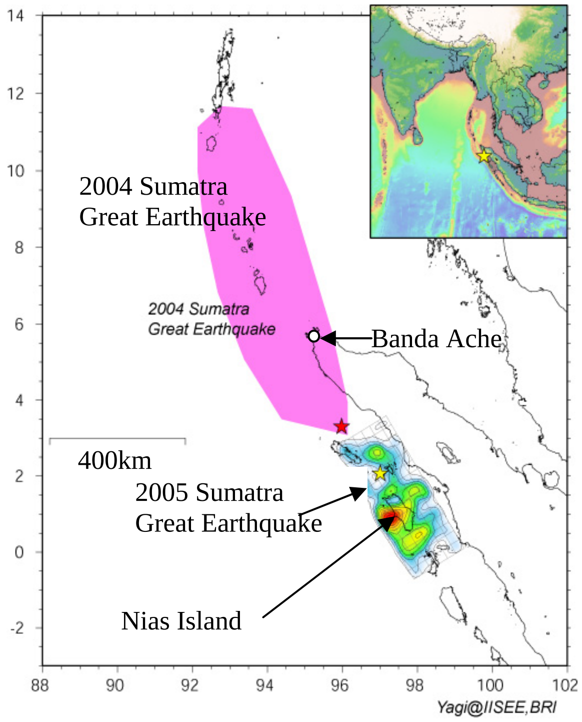


Figure 1: Epicenter and ruptured zone (revised by Yagi (2005))

Figure 2: Investigated area in Nias Island and locations of damaged structures and area

Nias island is about 150km long from north to south and about 50km wide from east to west, with a total population of 700,000. The economical centers are Gunung Sitoli in the north and Telukdalam in the south with concentrated population and buildings. The exact number of casualties and injured people is not well-known. They change depending upon the record sources. According to information of the United Nations[UN OCHA, 2005]., Casualties is more tha 850, and Injured people is more than 6000. Anyhow, the town of Gunung Sitoli on Nias Island is severly hit by this earthquake. The casulaties and injuries were mainly caused by the collapse of RC buildings and brick and wooden houses. Site investigations were carried out four times, twice in April, 2005 with support activities of providing expertise knowledge and recommendations, once in January, 2006 with support activity for training of local engineers for geotechnical investigations, once February, 2006. Figure 2 shows the inspection routes. The investigations were mainly conducted in eastern area, because inaccessible road conditions in western area at the time of the investigations. Typical damaged structures and major cities and towns are also shown in the figure.

3. TSUNAMI

The areas hit by tsunami were Singkil and Sibolga in Sumatra island, Simeulue island, Banyak islands, Nias island. The height of tsunami was 4m at Sngkil and Simeulue island, more than 1m at Sibolga. In Nias island, the effects of tsunami were observed at Tuhemberua in the north and Sorake beach in the south where wooden houses and two stories RC building in the areas were collapsed and heavily damaged. According to the residents of these locations, the height of tsunami was 4 to 5m and 6 to 7m, respectively. It is reported that tsunami was up to 2m high and settlement of ground was observed in Banyak islands [Pease Winds Japan (2005)]. The exact number of casualties by tsunami is not well-known. There were also reports of tsunami in another countories around the Indian Ocean, which were less than several ten cm. The tsunami induced by this earthquake was quite smaller as compared wtih that of the 2004 event.

4. STRUCTURAL DAMAGE

4.1 Damage to Bridges

The roads connecting Lahewa in the northern part of island to Gunung Sitoli, Gunung Sitoli to Telukdalam in the southern part along eastern coast, and Gunung Sitoli to Telukdalam through the center of island are main roads. Bridges in Nias Island may be broadly classified as Truss bridges, RC bridges, RC Box Culvert bridges, Wooden paved steel framed bridges, and Wooden bridges. Long span bridges are either truss bridges or RC bridges with or without box culverts. Truss bridges were especially used for long span bridges along main roads. The list of bridges and dominant forms of their damage are listed in Table 3 and locations of these bridges are shown in Figure 3.

The heavily damaged non-accessible large bridges within the surveyed area are Lafau bridge and Muzoi bridge in the northern coast between Gunung Sitoli and Lahewa route and Idano Gawo bridge between Gunung Sitoli and Telukdalam nearby Tetehosi at the eastern coast. These bridges mainly consist of truss super-structures with RC foundation piers or RC box culverts. The piers of Lafau bridge and Muzoi bridge were tilted and settled due to bearing capacity and lateral spreading problems associated with liquefaction of ground. The approach embankment road was settled and laterally moved towards the river due to liquefaction. Figure 4 and Figure 5 show damage of these bridges respectively. About 50 m to 70 m length of the approach embankment at the both side of Muzoi bridge is settled 4.5m in maximum and laterally moved towards the river, which can be clearly inferred from the tilted electric poles next to the bridge and the lateral movement of the ground was more than 4m on both sides. The piers were founded on piles. However piles were fractured at the pile top with exposing the reinforcement and not worked. The engineers of Department of Public Works pointed out that piers have piles reaching rock formation. It seems that the piles were designed against vertical loads and horizontal loads were not considered.

Figure 6 shows the damage of Idano Gawo bridge. The second pier of Idano Gawo bridge was tilted and slid towards the upstream side of the river and the box-culvert next to this pier was also tilted and slid together with the pier. The upper deck of the truss section of the bridge is horizontally shifted about 1.3m. The river flow is directed towards the pier and box-culvert. It seems that the toe erosion of the pier and box culvert, bearing capacity of foundation and large horizontal shaking may be the major causes of the damage to Idano Gawo bridge.

RC bridges and Truss bridge in Gunung Sitoli town were damaged by the lateral spreading of liquefied ground. The bridge foundations have some piles and some of these piles were broken at the top. The approach embankments of bridges are generally damaged and settled due to lateral spreading of ground and failure of wing-embankment walls. The settlements were generally greater than 30cm in many locations.

Table 3: List of bridges and its damages

Point No.	Subject	remarks
	East and North Coast Road of NIAS (Gunung Sitoli- Lahewa)	
1	RC 1Span (L=20m)	Crack at the approach embankment
2	RC bridge	Crack and settlement of the approach embankment
3	(I-type steel beam girder+ wooden floor)L=15m	Crack and settlement of the approach embankment
4	RC bridge L=8m	Crack and settlement of the approach embankment (1.2m)
5	(I-type steel beam girder+ wooden floor)L=21m	Crack and settlement of the approach embankment
6	RC bridge L=14m	Crack (W=5-30cm) and settlement of the approach embankment, crack and movement of the retaining wall, lateral displacement of ground
7	(I-type steel beam girder+ wooden floor)	Crack and failure of the approach embankment
8	(I-type steel beam girder+ wooden floor)L=15m	No damage
9	Damage of the road	crack of the road, collapse of the house by slope failure
10	Truss Bridge L=40m	Crack and settlement of the approach embankment, sand boil at the village near the bridge
11	Damage of the road	crack, slope failure
12	(I-type steel beam girder+ wooden floor)L=7.5m	No damage
13	(I-type steel beam girder+ wooden floor)L=11m	Severe Crack and settlement(1.2m) of the approach embankment
14	(I-type steel beam girder+ wooden floor)L=7m	Severe Crack and settlement of the approach embankment
15	Damage of the road	crack, liquefaction, tsunami
16	Damage of the road	crack, liquefaction, tsunami
17	(I-type steel beam girder+ wooden floor)L=19m	Crack and settlement of the approach embankment, difference in level (80cm), hardly to pass
18	Damage of the road	Crack, difference in level (50-100cm), hardly to pass
19	Sawo bridge: Truss 1Span 50m	Severe Liquefaction, Lateral Flow, Large amount of sand boil, Crack and settlement of the approach embankment, abutment of the left bank moved 30cm to the river
20	Muzoi Bridge RC 2span(10m each) +Truss 1span (51m)	Severe Liquefaction, Lateral Flow, settlement of the approach embankment (3-4.5m at the right, 0.2-1.5m at the left bank), movement of the abutment and the pier (400cm) to the river, piles were broken at the piletop, Truss moved, Impassable after the earthquake
21	Lafau bridge Truss 1span 55m	Severe Liquefaction, Lateral Flow, settlement of the approach embankment, movement of the abutment and the pier to the river, piles were broken at the piletop, Truss was dropped from the abutment at the right bank, Impassable after the earthquake
22	Lahewa port	a wharf collapsed and settled due to the separation from the piles.
	East and South Coast Road of NIAS (Gunung Sitoli- Telukdaram)	
101	Idano Goho bridge RC bridge 3 Span L=47m, Truss bridge 1Span	Lateral Flow, settlement of the approach embankment, movement of the abutment to the river, piles were broken at the piletop,
102	RC bridge 1 Span L=25m	Crack and settlement of the approach embankment, lateral flow
103	RC bridge 1 Span L=26m	Crack and settlement of the approach embankment
104	slope failure	Rock fall of porous limestone.
105	Truss bridge 1 Span L=60m	Settlement of the left approach embankment (50cm), abutment moved to the river, lateral flow
106	(I-type steel beam girder+ wooden floor)L=8m	Crack at the bank
107	(I-type steel beam girder+ wooden floor)L=8m	No damage
108	RC 3box culvert bridge L=15m	Small crack at the approach embankment, Good performance
109	RC bridge 1span L=36m	Crack and settlement of the approach embankment, Fall down of the abutment, piles were broken at the pile top.
110	Idano Sebua bridge RC bridge 3 Span L=50m	Crack and settlement of the approach embankment, Fall down of the abutment, lateral flow
111	RC ridge 2Span L=34m	Crack and settlement of the approach embankment, Fall down of the abutment, lateral flow
112	Truss bridge 1Span L=62m	Crack and settlement of the approach embankment, Fall down of the abutment, lateral flow
113	Idano Gawo bridge Truss bridge 2 Span L=80m, with Box Culvert bridge 28m on both side	Tilting of box culvert and pier at right side, Impassable after the earthquake
114	Truss bridge 1 Span L=30m	Crack and settlement (1.2m) of the right approach embankment, Fall down of the abutment, lateral flow, Truss moved
115	Idano Mizawo bridge Truss bridge 1 Span L=45m	Crack and settlement of the approach embankment, Fall down of the abutment, lateral flow, Truss moved
116	Idano Mola Bridge Truss bridge 2 Span L=60m	Crack and settlement of the approach embankment, Fall down of the abutment, lateral flow, Truss moved
117	Truss bridge 1 Span L=55m	Crack and settlement of the approach embankment, Fall down of the abutment, lateral flow, Truss moved (85cm)
118	RC bridge 1 Span L=25m	almost no damage
119	RC bridge 2 Span L=35m	almost no damage
120	RC bridge 1 Span L=25m	No damage
121	Susuwa Bridge Truss bridge 1 Span L=65m	Crack and settlement of the approach embankment, Fall down of the abutment, lateral flow
122	RC bridge 1 Span L=10m	No damage
123	Truss bridge 1 Span L=54m	Truss moved
124	Truss bridge 3 Span L=90m	No damage
125	Truss bridge 1 Span L=30m	No damage
126	slope failure	Rock fall of porous limestone.
127	slope failure	Rock fall of porous limestone.
128	Bailey bridge +wooden floor L=60m	almost no damage, Small crack at the approach embankment
129	Failure of the retaining wall at the seaside	Failure of the stone masonry retaining wall at the seaside
130	Telukdaram port	a part of wharf sank into the sea and some pile heads were fractured by collision of wharf segment.
131	Traditional wooden house	Good performance
132	Sorake beach	Tsunami
	West Coast Road of NIAS (Gunung Sitoli- Terukdaram)	
201	Idano Tanosaruru bridge Bailey bridge 30.5m	twisted and deformed, Crack and settlement of the approach embankment
202	Idano Oyo bridge (I-type steel beam girder+Bailey bridge+wooden floor) 55m	pier is tilted, settlement of the approach embankment
203	Idan Siwarawa bridge (Bailey bridge+wooden floor) 30.5m	collapse of abutment
204	Idano O'ou bridge (Bailey bridge+wooden floor) 185m	Bailey bridge is deformed

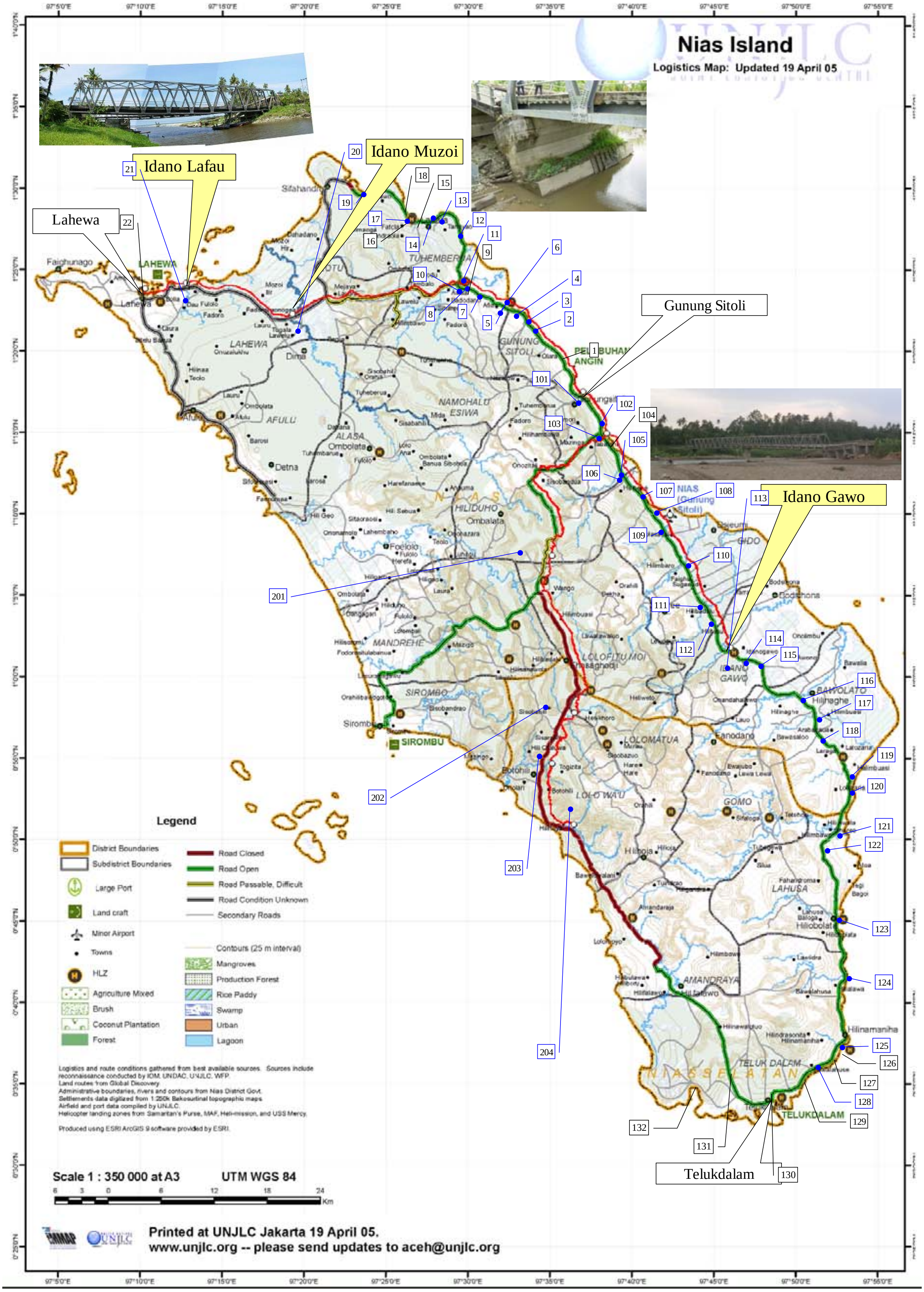


Figure 3: Investigated bridges and Major cites and towns

Many truss bridges along Gunung-Sitoli and Telukdalam route and along Gunung-Sitoli and Lahewa route were damaged by permanent movement of abutments as a result of lateral spreading of liquefied ground. The ground consists of mudstone-like layer, sand layer and clayey-silty soil and top organic soil from bottom to top. Sandy layer is generally found at the water level of river and it is expected to be full saturated. During earthquake shaking, it seems that this sandy layer is liquefied and caused the lateral spreading of ground. The lateral spreading of ground was particularly amplified on the convex side of the river bank as the ground can freely move towards the river. These movements caused high lateral forces on the abutments, which caused the sliding and tilting of piers or fractured the piles of the abutments of truss bridges. Similar situations are also observed on RC bridges.

The approach embankments of bridges are generally damaged and settled due to lateral spreading of ground and failure of wing-embankment walls. The settlements were generally greater than 30cm in many locations. The backfill materials of approach embankments consist of gravelly soil and it is expected that the potential of settlement or liquefaction is low. The bearing supports of many bridges do not have shear-keys or stoppers against both horizontal and vertical movements. Truss section horizontally shifted toward the upstream side or downstream side at some bridges.

The damaged bridges generally need to be re-constructed and it should be next to existing piers with necessary geotechnical investigation of ground and its characteristics. The present truss decks can be used in the new-constructions with some replacement of damaged elements and bolts and bearings together with appropriate stopper against horizontal and vertical relative movements.

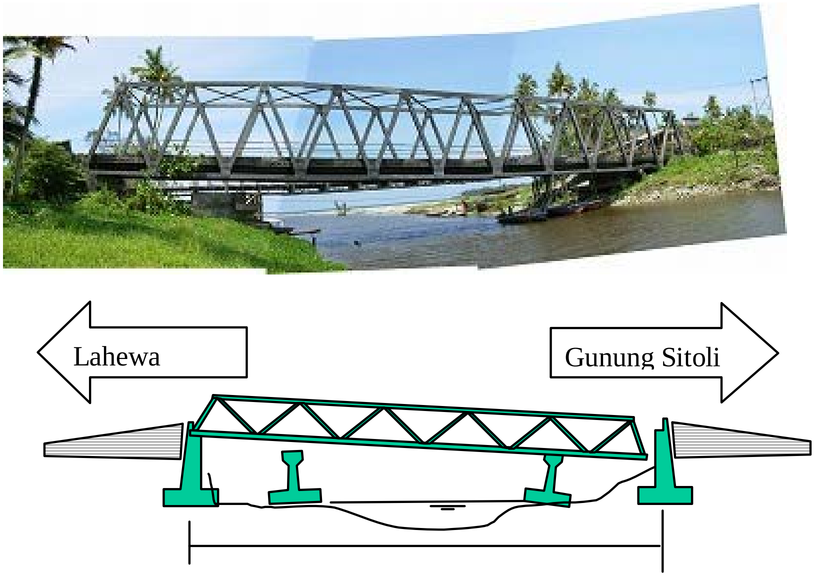


Figure 4: Damage of Lafau Bridge

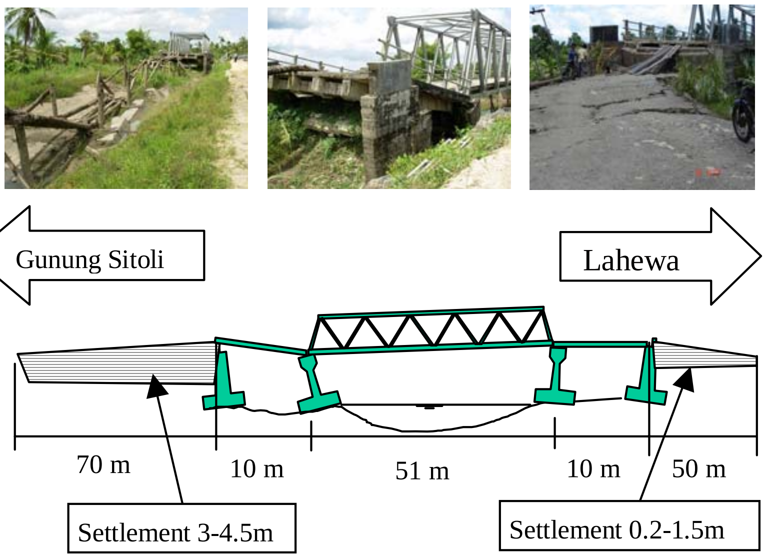


Figure 5: Damage of Muzoi Bridge

Figure 6: Damage of Idano Gawo Bridge

4.2 Damage to Roadways and Slope Failure

Roadways were damaged at many locations of the Nias island due to embankment failure, landslides, lateral spreading, of liquefaction. Many cracks and settlements more than 1m were observed. Roadways were generally narrow (less than 5m) and the asphalt surfacing of roadways were generally in poor condition having many potholes. Many rockfalls were observed particularly along the roadways passing through porous coral limestone. These rockfalls directly hit the roadways and obstructed roadways to traffic jast after the earthquake in some locations. There were many slope failures along the road in mountainous area between Gunung Sitoli and the west coast in the center of Nias island, where slopes consisted of weathered rock and closing roads to traffic.

4.3 Damage to Port Facilities

There was some damage to port structures in Nias island due to ground shaking. In Telukdaram new port in southern part of Nias island, a part of wharf sank into the sea and some pile heads were fractured by collision of wharf segment. The lateral spreading caused the fracturing and settlement of piles. The wharf of old Gunung Sitoli port located in the liquefied area, where many buildings were heavily damaged by settlement and tilting, was damaged by the lateral spreading of liquefied ground. As a result, the pile heads fractured and settled . Furthermore, there was a relative movement of 15cm between the sections of the wharf.

4.4 Damage to Buildings

RC buildings are generally found in large towns and large villages such as Gunung Sitoli, Telukdalam and Tetehosi. The concrete buildings having 2 or more stories were either collapsed in pancake mode or heavily damaged. The collapsed or heavily damaged RC buildings were almost located in low-land areas nearby shores and river banks. The main cause of casualties was the collapse of buildings in pan-cake mode. Figure 7 shows damages of buildings.

The reinforced concrete structures are framed structures with integrated or non-integrated in-fill walls. The reinforcing bars are generally smooth and infill walls are built with red-burned solid clay bricks using mortar. The floor height in the region ranges between 3 to 4m. The main causes of the collapse or heavily damage of the structures in this earthquake can be broadly classified as follows:

a. Fragile structural walls and lack of lateral stiffness,
b. Poor concrete quality and workmanship,
c. Plastic hinge development at the beam-column joints,
d. Lack of shear reinforcement and confinement,
e. Soft story,
f. Pounding and torsion
g. Ground motion characteristics (i.e. multiple shocks, long duration etc.) and
h. Soil liquefaction and lack of the soil bearing capacity in the coastal areas and nearby river banks.

There are many churches in Nias Island built as RC framed structures. The towers and main compounds of churches were all completely collapsed or heavily damaged and the causes of damage or collapses of churches were exactly the same as RC buildings.

The reclaimed area in the coastal region of Gunung Sitoli was strongly affected by the quake, settlement and lateral spreading of ground occurred. As a result, many buildings in such areas were heavily damaged with partial settlement, inclination and uplift of ground floor. The buildings without raft foundations and continuous tie-beams could not resist to ground failures due to liquefaction unless they are built on piles extending into the non-liquefiable layer. Figure 8 shows the damages of buildings due to liquefaction.

The collapses and heavy damage of RC buildings in Telukdalam town, which is about 150km from the epicenter, may be associated with soft ground condition in addition to the problems mentioned above. It seems that the ground shaking may be amplified in soft ground as it is the common case for shaking in coastal areas due to earthquakes in inter-plate subduction zones.

Figure 7: Pan cake failure of buildings

5. LİQUEFACTİON AND LATERAL SPREADİNG

As expected from the magnitude of this earthquake, the liquefaction of sandy ground is very likely. The sandy ground is observed along seashore and riverbanks. Damage of ground like settlement, lateral flow and associated structural damage due to liquefaction were widely observed in various locations along the coastal area and reclaimed ground. The damage induced in Gunung Sitoli due to liquefaction is widespread along the coastal area, reclaimed ground and riverbanks. The all possible forms of ground movements and the effects of ground liquefaction were observed such as sand boils, lateral ground movements, settlement. The lateral spreading of ground nearby bridge abutments were almost entirely associated with liquefaction of sand soil layer. Figure 9 shows grain size distribution curves for soil samples in Gunung Sitoli. It can be seen that these soils have almost the same grain size and they are very liquefiable. Swedish weight sounding tests were conducted at 2 points in Gunung Sitoli. Soil profile, converted SPT N-value from Swedish weight sounding test and Liquefaction Potential based on the result of geotechnical investigation are shown in Figure 10. Method of liquefaction assessment is according to the Recommendation for Design of Building Foundations, Architectural Institute of Japan. In this study, maximum acceleration of strong ground motion is taken as 350cm/s^2 for ultimate limit, which is as large as observed in liquefied area during Hyogoken-Nambu earthquake. There is a 3m thick loose sandy layer at the subsurface of reclaimed ground (shop house), which is inferred to be easily liquefiable from the result of Swedish weight sounding. As mentioned above, many buildings in such areas were heavily damaged with partial settlement, inclination and uplift of ground floor. As a result, almost all building were demolished and removed. At the site of Governor's house, there exist sandy layer, but having relatively large N-value and partially liquefiable during strong ground motion obtained from the assessment based on the test result. The elevation of the site is slightly higher than that of the reclaimed area and only small damages such as cracking in floor concrete were observed after the earthquake. The results obtained from geotechnical investigation are in good accordance with the observed damages caused by the earthquake. However, the geotechnical investigations of ground are scarce in Nias Island and it would be desirable to carry out such investigations in areas particularly affected by ground liquefaction in relation to recovery and reconstruction of Nias Island.

Figure 8: Effect of liquefaction and lateral spreading on RC building and truss bridge

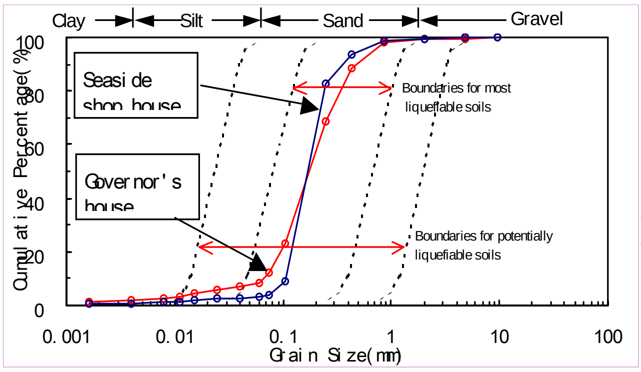
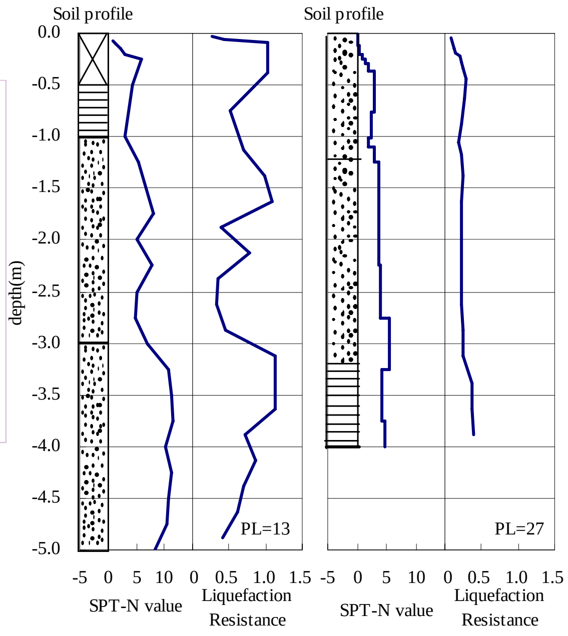


Figure 9: Grain size distribution curves for soils at 2 sites in Gunung Sitoli



a) Governor's house b) Seaside shop house

Figure 10: Soil profile, Converted SPT N-value from Swedish weight sounding test and liquefaction resistance at 2 sites in Gunung Sitoli

6. CONCLUSIONS

The conclusions obtained from the investigations in Nias island following the March 28, 2005 earthquake are summarized as follows,

1) A very large earthquake with a magnitude of 8.7 occurred nearby Nias Island of Indonesia on March 28, 2005. Strong ground motions induced heaviy casualties and damages to infrastructures such as road and bridges and buildings. Damage by tsunami were observed at Nias island and Banyak islands, however, the tsunami induced by this earthquake was quite limited than that of the last one.

2) Many bridges were damaged by strong ground motion and permanent movement of abutments as a result of lateral spreading of liquefied ground. The heavily damaged non-accessible large bridges within the surveyed area are Lafau bridge, Muzoi bridge and Idano Gawo bridge, which were mainly, consist of truss superstructure and RC abutments and piers. Many bridges were damaged

3) RC buildings having 2 or more stories generally found in cities and towns were cllapsed or heavily damaged in the pancake mode. The main causes of the damage of the structures in this earthquake can be broadly classified as follows: a) Fragile structural walls and lack of lateral stiffness, b) Poor concrete quality and workmanship, c) Plastic hinge development at the beam-column joints, d) Lack of shear reinforcement and confinement, e) Soft story, f) Ground motion characteristics and g) Soil liquefaction and lack of the soil bearing capacity in the coastal areas and nearby river banks.

4) The reclaimed area in the coastal region of Gunung Sitoli was strongly affected by the quake, settlement and lateral spreading of ground occurred. As a result, many buildings in such an area were heavily damaged with partial settlement, inclination and uplift of ground floor. The buildings without raft foundations and continuous tie-beams could not resist to ground failures due to liquefaction unless they are built on piles extending into the non-liquefiable layer.

5) The earthquake induced widespread liquefaction and lateral spreading. These phenomena were the primary cause of heavy damage to bridges and buildings in Nias Island. Damage of ground such as settlement, lateral spreading and associated structural damage due to liquefaction were widely observed in various locations along the coastal area and reclaimed ground.

6) Swedish weight sounding tests were conducted at 2 points in Gunung Sitoli. The results obtained from geotechnical investigation are in good accordance with the observed damages caused by the earthquake. However, the geotechnical investigations of ground are still lacking in Nias Island and it would be desirable to carry out such investigations in areas particularly affected by ground liquefaction for recovery and reconstruction of Nias Island.

7. ACKNOWLEDGEMENTS

The activities described in this paper are mainly as the activities of the Support Team of Japan Society of Civil Engineers (JSCE) for the Restoration and Rehabilitation of Infrastructures and Buildings and Joint Team of JSCE and Institution of Engineers, Indonesia (PII) for Instruction for Geotechnical Investigation and the Practical Utilization of its Results for Recovery and Reconstruction of Nias Island. A Part of this activity is supported by Infrastructure Development Institute – Japan. The contribution and the support for this work are highly appreciated. The author also would like to thank all members of many organizations in Indonesia and Japan for the cooperation and support to prepare material, to conduct investigation, to hold meetings, to provide training course in Nias island, Medan and Jakarta. We are also very thankful to local people for their cooperation, although they suffered most from the earthquake. Finally, we are honored and proud to be the first team of Engineers Without Borders, Japan to disaster area.

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Appendix 1

THE SUPPORT TEAM OF JSCE FOR THE RESTORATION AND REHABILITATION OF INFRASTRUCTURES AND BUILDINGS DAMAGED BY THE M8.7 NIAS EARTHQUAKE OF MARCH 28, 2005 IN NIAS ISLAND, INDONESIA, April 23 ~ 30, 2005 (First team)

1 PURPOSE

The Sumatra Earthquake of December 26, 2004 cause the most disastrous tsunami in Indian Ocean and severe disaster to the countries around the Indian Ocean, especially in Indonesia. Still more, another large earthquake occurred again at the west coast area of Sumatra and severe damage caused by strong ground motion in especially Nias Island.

Japan Society of Civil Engineers (JSCE) already dispatched a reconnaissance team to Banda Ache for the investigation into the damage to Infrastructures such as road, bridges, port facilities, riverbanks and lifeline systems in February. Also, JSCE dispatched an expert team of disaster prevention education to assist the educational activities for young people on tsunami and earthquake disaster cooperated with the concerned government agencies of suffered countries. They visited ten schools in Banda Ache for ad hoc lectures by using teaching materials such as Videos, textbooks and pamphlets in April as the start of this activity.

On the other hand, Many structures in Nias Island were damaged by strong ground motion during the large earthquake occurred March 28, 2005.

Temporary repairs and Rehabilitation of infrastructures, load, bridges and so on is on of the most urgent subjects in Indonesia. By the request of a state legislature, JSCE decided to dispatch an expert team to support the repair works and rehabilitation of public facilities.

The team was scheduled to visit Nias Island to investigate the damage of the infrastructure, and make recommendation for temporary repair and rehabilitation to concerned government agency.

Japan Society of Civil Engineers decided to dispatch a team of experts and engineers to Nias Island to support and to provide to provide expertise advices and technical assistance to the re-construction and restoration of infra-structures and to improve the seismic resistance of existing buildings with retrofitting from April 24 till 30. The team inspected all infrastructures and buildings through land-surveying.

The team consists of the members from Universities and engineers from construction companies directly involved on earthquake engineering members under the general coordination of Prof. Dr. M. Hamada from Waseda University and Chairman of Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers:

2. DISPATCED MEMBERS

- Prof. Dr. Ö. Aydan, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers,
  Tokai University, Department of Marine Civil Engineering
- Dr. Shigeru Miwa, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers,
  Tobishima Corporation
- Hiroyuki Komada, Senior Manager of Civil Engineering Division, Tobishima Corporation
- Tomoji Suzuki, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers, Secretary General of OISCA International, Indonesia

3. ITINERARY

The itinerary of the support team during inspection of infrastructures and buildings is as follows (Figure 1):

April 23, 2005: Leave for Indonesia. Arrival at Medan.

April 24, 2005: To inspect roadways and bridges and buildings between Gunung Sitoli and Lahewa (accessible as far as Muzoi River), tsunami traces

April 25, 2005: To inspect roadways and bridges, slopes and buildings between Gunung Sitoli and Sorake Beach (Telukdalam), port facilities at Telukdalam, tsunami traces,

April 26, 2005: To continue to inspect roadways and bridges, slopes and buildings between Sorake Beach (Telukdalam) and Gunung Sitoli, traditional houses at villages, Orahili in Telukdalam region

April 27, 2005: To inspect buildings in Gunung Sitoli and port facilities, presentation to local authorities and engineers at the Gunung Sitoli headquarters of Department of Public Works

April 28, 2005: To inspect buildings, roadways, bridges and slopes along the route between Gunung Sitoli and Lawa. Flying from Binanka Airport in Nias Island to Medan. Meeting, presentation of inspection results and recommendations to Vice-Governor of North Sumetra and involved authorities, including Mr Youpi, Parliament deputy for Nias and discussions

April 29, 2005: Luncheon at Consulate General in Medan with Consular General H. Hashi and Consul H. Orikasa and presentation of inspection results and recommendations including 2004 Aceh Earthquake & Tsunami, Leave for Japan

April 30, 2005: Arrival at Narita


Inspection Routes
and Locations
24 April
25-26 April
27 April
28 April
Tuhemberua
Lahewa
Away
GUNUNGSITOLI
Lasanga
Ombalata
Mandrehi
Hilibusi
P. NIAS
Budsuhara
Hiliweto
Onalimbu
Tekhnosi
Lolowau
Sirombu
Orahili
Lolomoyo
Helezalulu
Laguri
Tulukdalam
0
30km

JSCE (Japan Society of Civil Engineers)- PII (Persatuan Insinyur Indonesia (Institution of Engineers, Indonesia)) JOINT TEAMFORINSTRUCTIONS FOR GEOTECHNICAL INVESTIGATIONAND THE PRACTICAL UTILIZATION OF ITS RESULTS FOR RECOVERY AND RECONSTRUCTION OF NIAS ISLAND, January 1-8, 2006 (Second team)

1. PURPOSE OF DISPATCHING THE JSCE TEAM

A great earthquake with a magnitude of 8.5 hit North Sumatra, Nias Island on March 28, 2005. The earthquake caused extensive damage to mainly bridges, port facilities, houses and other buildings. Temporary repairs and Rehabilitation of infrastructures, load, bridges and so on is on of the most urgent subjects in Indonesia. By the request of a state legislature, JSCE dispatched the expert team to support the repair works and rehabilitation of public facilities in April 2005. The team visited Nias Island to investigate the damage of the infrastructure, and make recommendation for temporary repair and rehabilitation to concerned government agency.

However, in Gunug Sitoli, the capital of Nias Island, especially, due to liquefaction of the ground, its infrastructure including lifeline systems, which was seriously destroyed, has no prospect of being re-constructed yet. In order to initiate recovery and reconstruction work in the region, the soil exploration data such as boring data is essential. However, available data is scarce and not sufficient for recovery and reconstruction works at the present time.

Therefore, Japan Society of Civil Engineers decided to dispatch experts and engineers to Nias Island and provide the expertise advises and technical supports for recovering and re-construction with the close cooperation of the Institution of Engineers, Indonesia (Persatuan Insinyur Indonesia: PII).

In this project, some practical ground surveying methods such as Swedish Weight Sounding Test was introduced to local engineers for the prediction methods of ground liquefaction and their applications to the recovery and reconstruction of the damaged areas.

2. Roles of JSCE Team

The roles of The JSCE Team are as follows;

・Instructions on ground survey methods with Swedish Weight Sounding Test

・Instructions on prediction methods of ground liquefaction and counter-measures to ground liquefaction based on the data obtained from the ground surveys

・Instructions for applications of the obtained soil data to actual recovery and reconstruction projects

This project is expected to make a great contribution to the planning of recovery and reconstruction projects to be carried out in Nias Island and other disaster-affected regions. In addition, it will not only contribute to the planning of recovery and reconstruction projects to operate in the tsunami and earthquake stricken-regions on December 26, 2004, but also further training of specialist engineers.

3. DISPATCED MEMBERS

- Prof Dr. J. Kiyono, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers,
  Kyoto University, Department of Civil Engineering
- Prof. Dr. Ö. Aydan, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers,
  Tokai University, Department of Marine Civil Engineering

- Dr. Shigeru Miwa, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers,
  Tobishima Corporation
- Mr. Tomoji Suzuki, Member of Special Committee for Great Earthquake Disaster Management, Japan Society of Civil Engineers, Tobishima Corporation Indonesia office
- Mr. Ichiro ENDO, Member of JSCE, Taisei Kiso Sekkei Co., Ltd.
- Mr. Farman Ali, Persatuan Insinyur Indonesia (PII)Coordinator PII for JSCE Team
- Mr. Eddy Purnomo, PT. Geotech Konsultan Utama
- Ms. Yessi Dian Sari, PT. Geotech Konsultan Utama

4. ITINERARY

The itinerary of the support team during inspection of infrastructures and buildings is as follows

Date	Itinerary	Stay
Jan. 1 (Sun.)	1) Leave for Indonesia JL 725: Departure from Narita at 11:00/ Arrival at Jakarta at 17:05 2) 19:00 Meeting with Mr. Fukuwatari from Embassy of Japan	Jakarta Nikko
2 (Mon.)	1) 08:30 - 12:00 Internal Meeting 2) 16:00 - 17:30 Meeting with PII 3) 19:40 - 21:50 JAKARTA – MEDAN (GA 196)	Medan Polonia
3 (Tue.)	1) 08:30 - 10:00 Meeting with North Sumatra Head of Road & Bridge Office (Mrs. Roslila Sitompul) 2) 10:30 – 12:00 Courtesy call to Governor of North Sumatra 3) 14:00 - 16:30 Internal Meeting 4) 19:00 Meeting with Japan Consulate General	Medan Polonia
4(Wed.)	1) 07:00 - 08:00 MEDAN - NIAS (MZ 5424) 2) Meeting with BRR, Regency Head, Head of PU and Planning, etc 3) Boaring Test in Gunung Sitoli city (liquefaction / non liquefaction) 4) 20:00-22:00 Lecture class for engineers in Nias Island at Public Works Auditorium, Nias Regency	Nias Gunung Sitoli Dian Otomosi
5 (Thu.)	1) Boaring Test in Idano GAWO Bridge 2) Meeting with Regency Head, BRR 3) 20:00-22:00 Lecture class for engineers in Nias Island at Public Works Auditorium, Nias Regency	Nias Gunung Sitoli Dian Otomosi
6 (Fri.)	1) 08:40 - 09:50NIAS – MEDAN (MZ 5425) 2) 10:30 - 10:45 Meeting with Head of Road & Bridges Office, North Sumatra Province 3) Lecture class for engineers in North Sumatra Province 4) 16:30-18:00 MEDAN – JAKARTA 5) 19:00 Meeting with Japan Embassy Representative	Jakarta Nikko
7 (Sat.)	1) 08:00 Meeting with PII 2) Reports preparation 3) 22:30 - 07:25 JAKARTA – NARITA(JL726)	
8 (Sun.)	1) 07:25 Arrival at Narita	

Training on ground survey methods with Swedish Weight Sounding Test (Gunung Sitoli)

Training on ground survey methods with Swedish Weight Sounding Test (Idano Gawo Bridge)

Excellent engineers in the seminor

Training on ground survey methods with Swedish Weight Sounding Test (Liquefied area in Gunung Sitoli)

Training on the assessment methods of ground liquefaction and countermeasures against ground liquefaction based on the data obtained from the ground surveys

Meeting with Civil engineering Part of PII
(Jakarta)

Seminar at Road & Bridge office of North Sumatra Province (Medan)

Meeting with Road and Bridge office of North Sumatra Province

Donation of seismic code of Japan

JAPAN SOCIETY OF CIVIL ENGINEERS
Yotsuya 1-chome, Shinjuku-ku, Tokyo, 160-0004 JAPAN
PHONE: +81-3-3355-3441, 3452 FAX: +81-3-5379-2769, 0125 http://www.jsce.or.jp

Appendix 2:

Japan Society of Civil Engineers

Japan Society of Civil Engineers (JSCE) was established in 1914 with a mission to "contribute to the advancement of scientific culture and the development of society by promoting the field of civil engineering, developing civil engineering activities, and improving civil engineering skills" (from JSCE Constitution).

Three pillars of JSCE's activities are:
- Advancement of academic and technical fields
- Direct contribution to the global community
- Promoting exchange and new ideas

JSCE has over 40,000 members (as of Nov. 2005) consisting of educational and research institutions, construction companies, consultants, government offices and other relating organizations. Headquartered in Tokyo, JSCE holds 8 regional Chapters and 4 International Sections. Cooperation Agreement has been concluded with 24 equivalent overseas societies (as of August 2005). JSCE is a supporting organization of the Asian Civil Engineering Coordinating Council (ACECC), and thus taking on an ever -significant role in the international community.

The Organization for Promotion of Civil Engineering Technology (OPCET) was established in 2000 to assist the advancement of the civil engineering profession. One of the major activities is promoting Civil Engineers' Qualification System of JSCE: mutual recognition of the qualification system with the Cooperation Agreement societies is in process.

Advancement of Academic and Technical Fields

JSCE works in collaboration with its peer societies to collect information and to engage in studies and researches in the civil engineering field.

More than 30 committees work conduct extensive studies and researches pursuing the state-of-art civil engineering technologies. The findings are shared widely throughout the civil engineering community, presented in lectures and symposiums, or published in forms of books.

In addition, the society offers JSCE Awards every year to recognize the outstanding engineers, civil engineering works, and newly developed technologies that have made considerable contributions to the civil engineering profession.

Direct Contribution to the Global Community

JSCE contributes to the global community for its betterment:

- Dispatching investigation/ technical support teams to large-scale disaster affected areas to analyze causes
- Of the total 34 teams dispatched since 1998, 16 were to countries abroad
- Introducing experienced civil engineers through JSCE's Registration & Recruiting System of Senior Civil Engineers, and assisting to improve future civil engineering quality through Civil Engineer's Qualification System of JSCE
- Introducing the most current activities of JSCE on its website

JSCE has dispatched investigation teams to disaster-stricken areas thirteen times since 1999. The current ones are to Sumatra Island right after the 2005 Sumatra Earthquake and to Pakistan soon after the 2005 Kashmir Earthquake. Another team is going to Pakistan to conduct further investigations on-site.

Promoting Exchange and New Ideas

JSCE provides the members with information, forums and opportunities of social and academic activities for encouraging active exchange and the improvement of their professionalism.

Information Provision

Publications include the monthly magazine "Civil Engineering" in Japanese and quarterly journals. A quarterly English newsletter is published for the members residing outside of Japan.

Opportunities for Exchange

The JSCE Annual Meeting is held in fall, featuring International Roundtable Meeting, academic lectures and panel discussions on current issues surrounding the civil engineering profession. For overseas guest, special programs are arranged to encourage active exchange with their colleagues.

The International Summer Symposium and Student Tour Grant are a few of the opportunities of international exchange.

Joint seminars, symposia and workshops are organized with the Cooperation Agreement societies throughout the year.