STUDIES ON SOIL LIQUEFACTION OBSERVED DURING THE MIYAGI-KEN OKI EARTHQUAKE OF JUNE 12, 1978

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SUMMARY

A severe earthquake hit the north eastern part of Japan on June 12, 1978, registering a Richter magnitude of 7.4. In this earthquake, soil liquefaction phenomena were observed at many sites. Some of bridges, dykes, harbor facilities were damaged near the liquefied sites. Sketchy and detailed investigations on liquefaction were conducted after the earthquake. The investigations on general conditions of 30 liquefied sites, and on detailed analyses at Natori River Dyke and Yuriage Bridge sites were carried out. As a result of the investigations, proposals for improving procedures for assessing soil liquefaction and examinations of the procedures were made, and the effects of soil liquefaction on structures were quantitatively evaluated.

LIQUEFIED SITES

In this earthquake, soil liquefaction were observed at 30 areas[1]. Locations of occurrence of soil liquefaction are indicated in Fig. 1. Open circles in the figure denote areas where soil liquefaction took place. It is seen from the figure that soil liquefaction were occurred at alluvial lands. Occurrence of liquefaction was defined here from visual evidences of sand boils spouting from grounds. Each area represented by a circle in the figure normally had a number of points of sand boils within a small area. Table 1 gives brief informations of the liquefied sites. Numerals in the table coincide with those in open circles in Fig. 1.

Engineering structures such as river dykes and highway bridges were damaged in 22 liquefied areas. In the remaining 8 liquefied areas, no structural damages were observed. Typical examples of soil liquefaction in this earthquake are shown in Photo. 1 and Photo. 2. Photo. 1 indicates the sand boils observed near river dykes and Photo. 2 at a bridge.

Epicentral distances of liquefied areas in this earthquake are between 80 and 114 km. The farthest distance was 114 km, which coincides well with the following empirical equation derived in the previous study[2].

$$\log_{10} R = 0.77\ M - 3.6 \qquad (1)$$

where M denotes the Richter magnitude, and R is the farthest epicentral distance of areas where liquefaction may take place. This relation is shown in Fig. 2, together with the plot of the case of the 1978 Miyagi-ken-oki Earthquake.

SOIL CONDITIONS AT LIQUEFIED SITES

Features of Sand Boils

In sketchy investigations, sand boils were gathered at several liquefied sites. Fig. 3 shows the relationship between grain size of sand boils

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and accumulative percentage of weight. Distributions of grain size of sand boils are uniform and mean particle diameters range from 0.22 (mm) to 0.50 (mm).

Micro-topographical Features at Liquefied Sites

Based on the previous studies on topographical features at liquefied sites, liquefaction potentials closely relate to the topografical features of objective sites. This was confirmed again in this earthquake. Fig. 4 (A) shows the classifications of liquefied sites on micro-topographical features. In this figure, it is evident that liquefaction mainly took place at present river beds, reclaimed lands and flood plains.

As mentioned above, it is supposed that there are typical differences of micro-topographical features between liquefied sites and non-liquefied sites. To microzone liquefaction potentials, the standards of micro-topographical features shown in Table 2 are proposed. The classifications in the table are based on the experiences of liquefaction phenomena during past earthquakes. A result of application of the classifications in Table 2 for liquefied sites in this earthquake is shown in Fig. 4(B). In this figure, the percentages of Class A, Class B and Class C are 65(%), 35(%) and 0(%), respectively. Using Table 2, judgement of liquefaction potentials and necessity for simplified or detailed investigations on liquefaction can be done simply only by the data of micro-topographical features at the sites for extensive areas.

SIMPLIFIED METHOD FOR ASSESSING SOIL LIQUEFACTION POTENTIAL

The Public Works Research Institute has proposed a simplified method for assessing soil liquefaction potential of sandy deposits[3]. In the method an ability to resist the liquefaction occurrence of a soil element at an arbitary depth can be expressed by the factor of liquefaction resistance (F_L).

$$F_L = \frac{R}{L} \tag{2}$$

In Eq. (2) R is the insitu resistance (or dynamic strength) of the element, and can be obtained by laboratory cyclic triaxial tests using undisturbed sand samples at objective layers. Without detailed laboratory tests, R can be simply evaluated by

$$R = \begin{cases} 0.0042\ D_r^* + 0.19 & (0.02\text{mm} \leqq D_{50} \leqq 0.05\text{mm}) \\ 0.0042\ D_r^* + 0.225\ \log_{10}\left(\frac{0.35}{D_{50}}\right) & (0.05\text{mm} < D_{50} \leqq 0.6\text{mm}) \\ 0.0042\ D_r^* - 0.05 & (0.6\ \text{mm} < D_{50} \leqq 2.0\text{mm}) \end{cases} \tag{3}$$

where $D_r^* = \sqrt{N/(\sigma v' + 0.7)}$, N = number of blows by the standard penetration test, σ_v' = effective overburden pressure (in kgf/cm^2), and D_{50} = mean particle diameter (in mm). On the other hand L is the dynamic load induced in the soil element by a seismic motion, and is estimated by dynamic response analyses of grounds. Without dynamic analyses, L also can be simply estimated by

$$L = \frac{\tau_{max}}{\sigma_v'} = \frac{\alpha_{smax}}{g} \cdot \frac{\sigma_v}{\sigma_v'} \cdot r_d \tag{4}$$

where τ_{max} = maximum shear stress (in kgf/cm^2), α_{smax} = maximum ground surface acceleration (in gals), g = acceleration of gravity (=980 gals), σ_v = total overburden pressure (in kgf/cm^2), and r_d = reduction factor for dynamic shear stress accounting for deformation of the subsoil. As for r_d, an average relation

$$r_d = 1 - 0.015 \cdot Z \quad (Z = \text{depth in meters}) \qquad (5)$$

can be assumed for alluvial deposits. From a spacial distribution of F_L-values for the site concerned, liquefaction potential may be evaluated.

DETAILED INVESTIGATION ON SOIL LIQUEFACTION

After the earthquake, detailed investigations on soil liquefaction were carried out at three typical areas, i.e. Nakamura Dyke, Yuriage-kami Dyke and Yuriage Bridge.

At these areas insitu soil tests, shear wave measurement, sand sampling, laboratory cyclic triaxial tests, dynamic response analyses of grounds, and assessment of liquefaction have been conducted. The assessment of liquefaction was done by appling the concept of the factor of liquefaction resistance (F_L) defined in Eq. 2. R and L were estimated by both detailed data based on laboratory tests and dynamic analyses (one-dimensional wave propagation method), and simplified analyses using Eq. 3 and Eq. 4.

Natori River Dykes

River dykes were damaged at several places along Natori River. Damages at two areas, Nakamura Dyke on the left bank (L 2.8 km) and Yuriage-kami Dyke on the right bank (R 2.4 km), will be introduced in the following. Fig. 5 shows an enlarged plan of Nakamura Dyke, where sand boils were observed at numerous points. It should be noted that the same area had once been liquefied and the dyke had been damaged during the February 20, 1978 Earthquake (M = 6.8). Fig. 6 illustrates damage features at this place where the dyke settled over a length of 110 m. The maximum settlement was 1.22 m. Fig. 7 shows a plan of Yuriage-kami Dyke, where sand boils and dyke cracks were observed. This area was also damaged slightly during the February Earthquake.

Fig. 10 and Fig. 11 illustrate results of soil profile, N-values, D_{50} and factors of liquefaction resistance (F_L) at Nakamura Dyke and Yuriage-kami Dyke, respectively. In these areas sand boils were observed at points N-4, N-5, Y-1 and Y-2. No sand boils occurred at points N-1, N-2 and Y-3.

In detailed analyses the ground acceleration recorded on the rocky layer at Kaihoku Bridge in this earthquake was inputted as a base acceleration. The maximum accelerations of 100 gals and 150 gals were taken for the analyses. In simplified analyses, three levels of maximum ground accelerations α_{smax} (in Eq. 4), i.e. 180, 240 and 300 (gals) were supposed, in view of the measured strong-motion records nearby. N-values, σ_v' and D_{50} in Eq. 3 were decided on measurements. It is found from these figures that sand boils occurred at the sites which had F_L-values almost less than 1.0. From this fact F_L-value can indicate the liquefaction potentials.

Yuriage Bridge

Yuriage Bridge close to the mouth of Natori River was damaged heavily. Eight piers except Pier 2 were cracked with the severest at Pier 1.

Damage features of the bridge is detailed in other paper[4]. As shown in Fig. 12, after the earthquake sands spouted from cracks at numerous points near Pier 5 and between Piers 7 and 9. At these points ground surfaces settled about 10 cm relative to the Piers.

The results of liquefaction assessment are illustrated in Fig. 13. In the figure F_L-values were estimated at five boring points; B-1, B-2, B-3 (sand boils observed), B-4 (sand boils unconfirmed because of stream) and B-5 (no sand boils). In detailed analyses, the maximum input acceleration recorded at Tarumizu Dam in this earthquake was taken as 180 gals at the depth of 42 m. On the other hand, in simplified analyses, maximum ground accelerations (α_{smax}) were supposed to be 180, 240 and 300 gals.

According to this figure, F_L-values less than 1.0 distribute nearly at the depth of 2 - 6 m (B-1), 2 - 5 m (B-2), 1 - 8 m (B-3), 1 - 7 m (B-4) and 3 - 9 m (B-5). At B-5, F_L-values are greater than 1.0 near the surface. It is supposed that at points B-1, B-2, B-3 and B-4, liquefaction took place at the layers from the surface to the above-mentioned depths, and that at point B-5 liquefaction did not occur near the surface (up to about 2 m) but might have occurred at a deeper layer (between 3 to 8 m). In the case of Yuriage Bridge, F_L-values also correspond with sand boils phenomena, as well as the case of Natori River Dykes.

CONCLUSIONS

From the studies on liquefaction observed during the Miyagi-Ken-Oki Earthquake of 1978, the following conclusions can be reduced.

1) Soil liquefactions took place within the farthest epicentral distance defined by Eq. 1.

2) Liquefaction phenomena closely relate to micro-tropical features. In this earthquake, sand boils mainly occurred at present river beds, reclaimed lands and flood plains.

3) The factor of liquefaction resistance F_L can be used effectively for the assessment of liquefaction potential. And both of the simplified method with use of N-values, mean particle diameters, and overburden pressures and the rigorous method with use of dynamic triaxial tests on undisturbed specimens are effective.

ACKNOWLEDGEMENTS

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Table 1 Brief Description of Liquefied Sites (See Fig.1 for Locations)

No.	River or Place	Site	Epic.Dist. Δ (km)	Evidence of Liquefaction	Damaged Structures	Typical N-values Depth 2	5	10	15	20m
1	Abukuma	Abukuma Br.	114	Sand Boils	Bridge Piers	14	17	16	56	21
2	"	Niihama Weir	111	"	Rivetments	7	2(S)	30	32	-
3	"	River Mouth	110	"	Dyke	2	12	16	18	17
4	Arahama	Kokumin Ctr	110	Sand Boils,Cracks	Tank, Pool	5	12	36	37	45
5	Torinoumi	Shimayazaki	112	Sand Boils	Dyke,Rivetments			—		
6	Natori	Natori Br.	112	Sand Boils,Cracks	None			—		
7	"	Nakamura	109	Sand Boils	Dyke	4	17	19	-	-
8	"	Yuriage-Kami	109	"	Dyke	4	2(S)	50	50	-
9	"	Yuriage Br.	108	Sand Boils,Settle	Bridge Piers	3	8	25	25	15
10	Sendai New Port	New Port	102	Sand Boils	Pavement	12	17	24	29	7
11	Yoshida	Yamazaki	106	"	Dyke	2	3	0(C)	6	16
12	Naruse	Kimazuka Br.	99	"	Bridge			—		
13	Eai	Wabuchi	95	"	Dyke			—		
14	Old Kitakami	Oiri (1)	92	"	Dyke	2	9	3(S)	45	4(C)
15	"	Oiri (2)	91	"	Dyke			—		
16	Kitakami	Kawamae	85	"	Dyke			—		
17	"	Magaki	80	"	Dyke	3	9	6	3(C)	-
18	Ishinomaki Port	Ohmagari	87	"	Coastal Protection			—		
19	Kyu Kitakami	Uomachi Port	80	"	Rivetment, Apron	6	4	7(S)	1(S)	50
20	Ishinomaki C.	Hebita	86	"	None	2	5	28	6(S)	4(S)
21	Suzakihama	Suzakihama	93	"	None			—		
22	Takagi	Matsushima	100	"	Tank, Pump Stn.	0(S)	2(S)	0(S)	0(S)	2(S)
23	Matsushima	Tedaru	98	"	None			—		
24	Rifu	JNR	107	"	None	6	4	0(S)	4	8
25	Sendai New Port	Power Stn.	102	"	None	12	20	25	23	7
26	Old Hazama	Yoneyama	104	"	None	5	10	11	19	47
27	Hazama T.	Municipal Off.	104	"	None			—		
28	Yoshida	Fukuro	109	"	Dyke	3	30	4(S)	1(S)	18
29	Ishinomaki Port	Shiomi	84	"	Pier	4	12	13	5(S)	3(S)
30	Eai	Kamiyaji	105	"	Dyke	1	3	13	18	5(S)

(Note) In the column of N-values, (S) and (C) denote silt and clay, respectively, no parenthesis indicates sand or gravel.

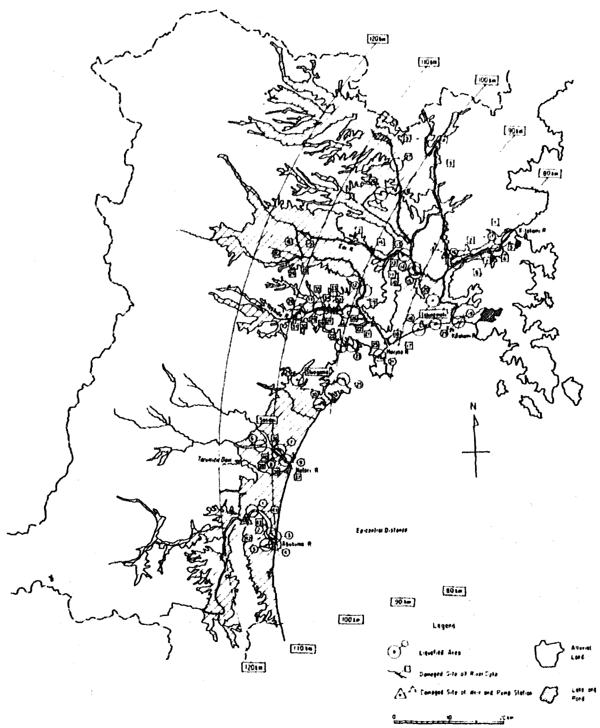


Fig. 1 Distribution of Liquefied Sites and Damaged River Engineering Structures

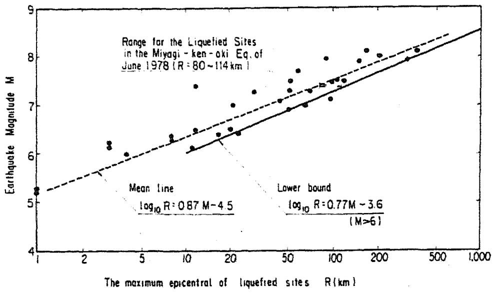


Fig. 2 Relationship between the Maximum Epicentral Distance of Liquefied Sites R and Magnitude M

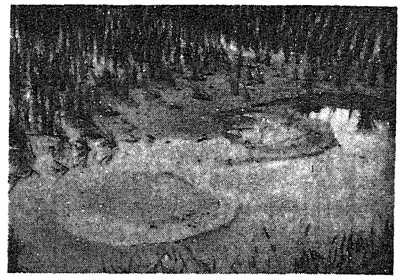


Photo. 1 Sand Boils at the Rice Field, Oiri (1) (Old Kitakami River)

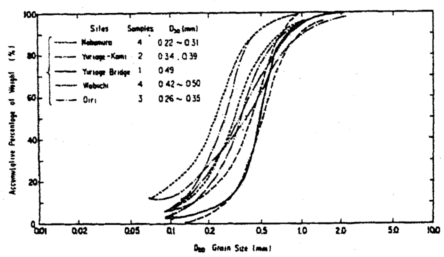
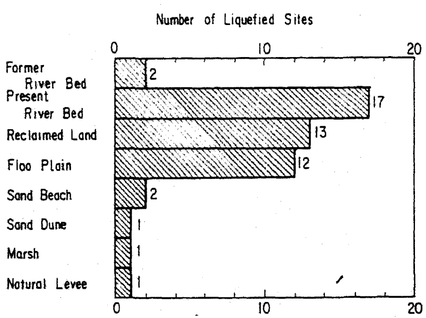
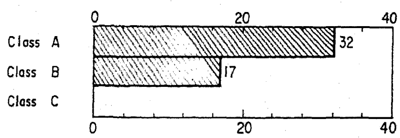


Fig. 3 Distribution of Grain Size of Sand Boils

Photo. 2 Sand Boils from Cracks on Ground near Pier 8, Yuriage Bridge (Natori River)



(A) Micro-topographical Features at Liquefied Sites



(B) Classifications of Liquefied Sites

Fig. 4 Micro-topographical Features

Table 2 Standards for Classifications of Liquefaction Potentials

	Classifications	Standards of micro-topographical features
A	An area with high probabilities of liquefactions (An area needed detailed investigations)	• Former River Bed • River Bed • Lowland between sand dunes with high water level • Water Area • Area (highly) embanked at the water area • Reclaimed Land
B	An area with probabilities of liquefactions (An area needed simplified investigations)	Area not applied to Class A and Class C
C	An area with low probabilities of liquefactions (An area not needed investigations)	• Mountain • Hill • Platform

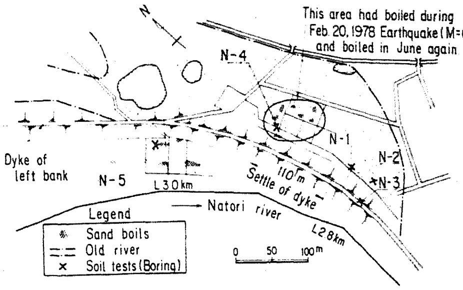
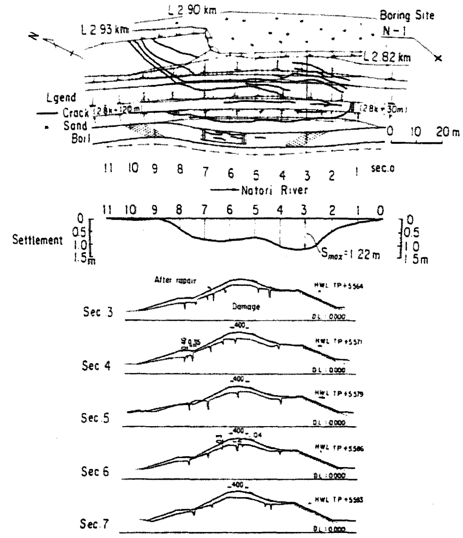


Fig. 6 Damage Feature at Nakamura Dyke



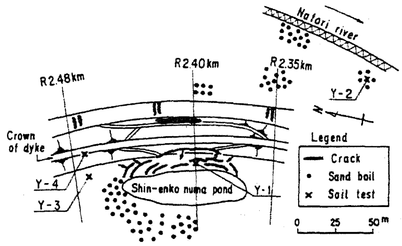
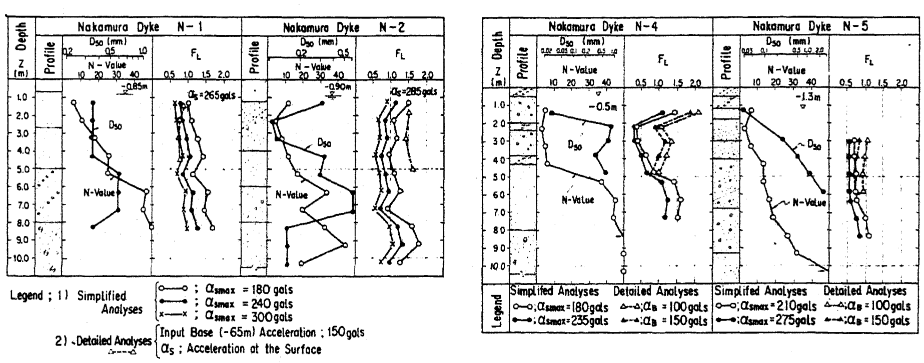


Fig. 7 Plan of Yuriage-kami Dyke and Points of Soil Tests

Fig. 5 Plan of Nakamura Dyke and Points of Soil Tests



(A) N-1 and N-2 (at liquefied sites)

(B) N-4 and N-5 (at non-liquefied sites)

Fig. 8 F_L-values at Nakamura Dyke

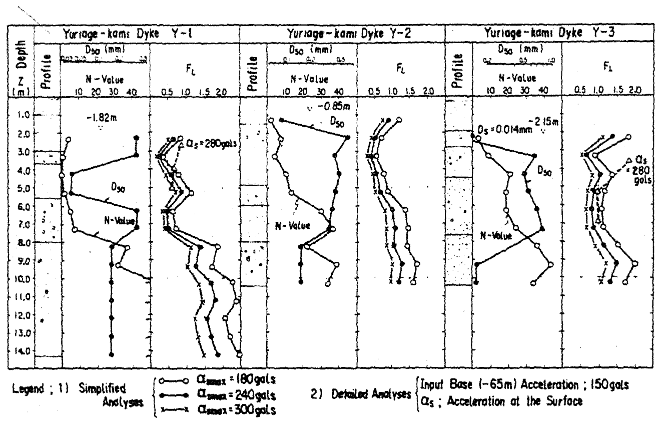


Fig. 9 F_L-values at Yuriage-kami Dyke
(Y-1, Y-2; liquefied, Y-3; non-liquefied)

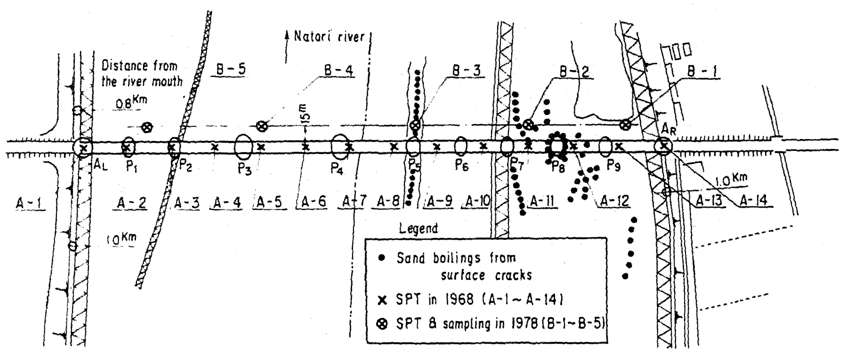


Fig. 10 Points of Sand Boils and Insitu Soil Tests at Yuriage Bridge

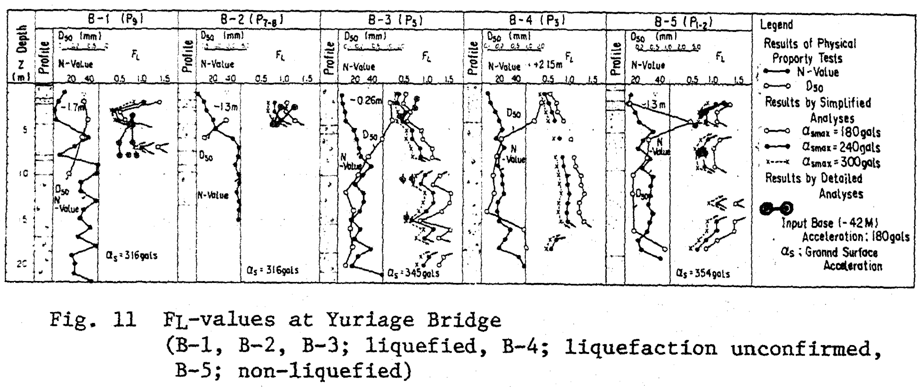


Fig. 11 F_L-values at Yuriage Bridge
(B-1, B-2, B-3; liquefied, B-4; liquefaction unconfirmed, B-5; non-liquefied)