ANALYSIS OF LIQUEFACTIONS DURING THE 1978 OFF MIYAGI PREFECTURE EARTHQUAKE

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SUMMARY

An earthquake of magnitude 7.4 hit the northern part of Honshu of Japan in June 1978. The maximum value of recorded horizontal component acceleration was 293 gals. By the earthquake ground motions, sandy grounds at many places were forced to liquefy. In this paper four sites of liquefaction and two sites of non-liquefaction were selected and site conditions and behaviours of the grounds were described with results of analysis.

INTRODUCTION

An earthquake of magnitude 7.4 hit the northern part of Honshu of Japan on June 12, 1978. This earthquake was named as "1978 Off Miyagi Prefecture Earthquake (1978 nen Miyagi-ken Oki Jishin, in Japanese). By the earthquake strong ground shakings were generated and liquefactions of sandy grounds took place at many places in the area of strong ground shakings.

There are many reports on liquefactions which had been caused by the earthquakes before the 1978 Off Miyagi Prefecture Earthquake; however, only few of them are effective for analyses in details. For the analyses, information is essential on input ground motions from the baserock to the surface layer and properties of the surface layer. Ground motions caused by the 1978 Off Miyagi Prefecture Earthquake were recorded at many places. Especially, two strong-motion accelerographs installed on rock succeeded in recording the entire ground motions at their locations. These records provide excellent information on the input ground motions. Therefore, if there are sites of liquefaction or non-liquefaction associated with good information on properties of grounds, they can be good case records for the liquefaction study.

In this paper, four liquefaction sites and two non-liquefaction sites are selected and the evidences of liquefaction or non-liquefaction at the sites will be presented together with the information on earthquake ground motions and properties of the grounds. Results of the analysis based on earthquake response calculation and dynamic tri-axial compression tests will be presented also.

EARTHQUAKE AND GROUND MOTIONS

Location of epicentral region is shown in Fig. 1(a) and (b). The x-mark in Fig. 1(b) shows the location of epicenter and the square area indicated by the broken line shows the location of fault plane. The arrow shows the direction of slip and the amount of slip was estimated as about 1.7 meter.

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SITE DESCRIPTIONS

Site A

This site is behind a steel sheetpile bulkhead. Rock formation starts from 58.7 meter depth. There is a stiff layer (N-values exceed 50) from about 30 to 36 meter in depth. The N-values of the remaining parts are mostly less than 20. The liquefaction was evident from the sand boil. The extensive displacement of the sheetpile top (about 57 cm in maximum) also supports the view that the soil liquefied at this site.

Site B

This site is behind a steel sheetpile bulkhead. A stiff sandy gravel layer appears at 43.3 meter depth. The N-values of this layer exceed 50. No rock formation was found from the boring up to 45.2 meter depth. The N-values of the overlying layer are between 5 and 1.5. The ground at this site was originally not much different from that at the site C. For accelerating consolidation of a clay layer under rather stiff sand layers, sand piles were placed through the sand layers. The water jet was used to dig the holes for the pile, and the water jet loosened the sand layers. The liquefaction was evident from the sand boil and the damage to the bulkhead.

Site C

This site is behind a steel sheetpile bulkhead. The area represented by the site C borders the area repesented by the site B. The sand boil was not seen at this site. No damage to the bulkhead was caused. Therefore, it was reasonable judgement from the engineering viewpoint that the liquefaction did not take place at this site.

Site D

This site is also behind a steel sheetpile bulkhead. Within 27 meter in depth, no stiff layer was found even from the boring in the vicinity of this site. The evidences of liquefaction were sand boil at many points and the damage to the bulkhead. The center line of asphalt pave road was deflected toward the sea. The line was straight originally. This may be implying that land displacement of small extent took place at the time of the earthquake. It is not clear whether the slide was related with the liquefaction or not.

Site E

The ground of this site and that of the site D were filled lands constructed simultaneously. Presently, however, this site is used for oil storage tank yard, and the ground have been compacted at the time of the tank construction by the sand compaction pile method. Any remaining influence from the ground motions was not seen. No sand boil was observed.

Site F

As it has been explained, the ground condition at this site was originally almost identical with that of the site E. Sand boils were seen at many points in the area around this site, even at the border between the sites E and F. No structure existed at this site.

There were two accelerographs installed on rock outcrop. One was at Ofunato city which is shown in Fig. 1(b). The epicentral distance of this accelerograph site is 103 km. The maximum horizontal component acceleration was 170 gals in E41S direction. (Kurata, et al, 1979) The other accelerograph was located in Ishinomaki city. The instrument site is shown in Fig. 1(c). The epicentral distance was 80 km; however, the distance from the instrument site to edge of the epicentral region was 25km. The maximum horizontal component acceleration was 293 gals in E42S direction. (Iwasaki, et al, 1978) The time histories of both records are shown in Fig. 2.

Both accelerographs are of the SMAC-B2 type and the maximum accelerations mentioned are uncorrected ones. After the instrument correction to extend the frequency range up to 10Hz, the maximum accelerations at Ofunato and Ishinomaki are 275 gals and 387 gals, respectively.

LIQUEFACTION AND NON-LIQUEFACTION SITES

All the six sites selected for the presentation and the analysis are in Ishinomaki as shown in Fig. 1(c). The sites A, B, D, and F are liquefaction sites and the sites C and E are non-liquefaction sites. They are in short distances each other. The sites are not far from the strong-motion accelerograph site, within about 5 km.

The strong-motion earthquake records at Ofunato and Ishinomaki have a little different frequency characteristics each other; and calculated ground surface accelerations depend on which record is used as the input baserock motions. In this study, however, the records at Ishinomaki was used as the input baserock motions, because it was recorded in the vicinity of the sites under the study.

Soils in upper 15 meters of the grounds at all the sites are shown in Fig. 3, together with the N-values of standard penetration tests. The grain-size distribution curve of soil near the ground surface at the site B is shown in Fig. 4. The grain-size distribution curves of soils at the site A, C, and D are almost identical with the curve in Fig. 4. In Fig. 4, the grain-size distribution curve of the Bandaijima sand is also shown. The Bandaijima sand is a sand in Niitata, which liquefied at the time of the Niigata earthquake of 1964.

The grain-size distribution curves of soils at the sites E and F are not available. The curves in Fig. 5 are the grain-size distribution curves of soils in the vicinity of the sites. They were samples at several points within about 200 meters from the sites.

All the six sites have artificially filled sand of few meter thickness at their top of grounds. Exact thickness of the filled sand is not recorded. The fill material was dredged from the sea bottom during the construction of the navigation channels in the ports. The conditions of the six sites as well as the damage to the structures are reported in a separate report (Tsuchida, et al., 1979).

ANALYSIS

Grounds of all the sites were idealized into lumped mass models, each model had six masses. With the acceleration time history at Ishinomaki as the input motions, responses of the grounds were calculated. In this calculation, the soils were considered as linear materials; however, their shear moduli were modiffied taking strain amplitude into consideration. Effect of pore-water pressure increase to the shear moduli was not considered in this analysis. Calculated ground surface accelerations are presented in Table 1.

No dynamic shear test with the sands at the sites has been made. However, as it is seen in Fig. 4, the grain-size distributions of the sands at the sites are similar to that of the Bandaijima sand; and the results of the dynamic tri-axial compression test of the Bandaijima sand are available. The results were used in this analysis.

Shear stress averaged in each layer was calculated from the results of response analysis. Then, it was converted into an equivalent cyclic stress of uniform amplitude τ_{eq} and of N_{eq} cycles. N_{eq} was compared with the number of stress cycles to cause liquefaction, N_{ℓ}, for the stress amplitude τ_{eq}. Results are shown in Table 1.

When the ratio, N_{eq}/N_{ℓ}, is larger than unity, it indicates liquefaction. A, B and E, the analysed results are not consistent with observations. There is, of course, some possibility to choose different valuse for the parameters of the models; and the models with such values may give different results from those of the present analysis. However, it is believed that the values used in this analysis are also among the reasonable estimates from the practical point of view. Therefore, it is considered that further improvement on the analytical procedure including the determination of parameter values is nesessary.

CONCLUSIONS

Six case records of liquefaction and non-liquefaction were presented. The cases were analysed and two liquefaction sites were estimated not to liquefy. One non-liquefaction site was estimated to liquefy. For the other cases, analyses were consistent with the real performances of grounds at the sites. From the practical point of view, further improvement on analytical procedure including the determination of parameter values seems to be necessary.

REFERENCES

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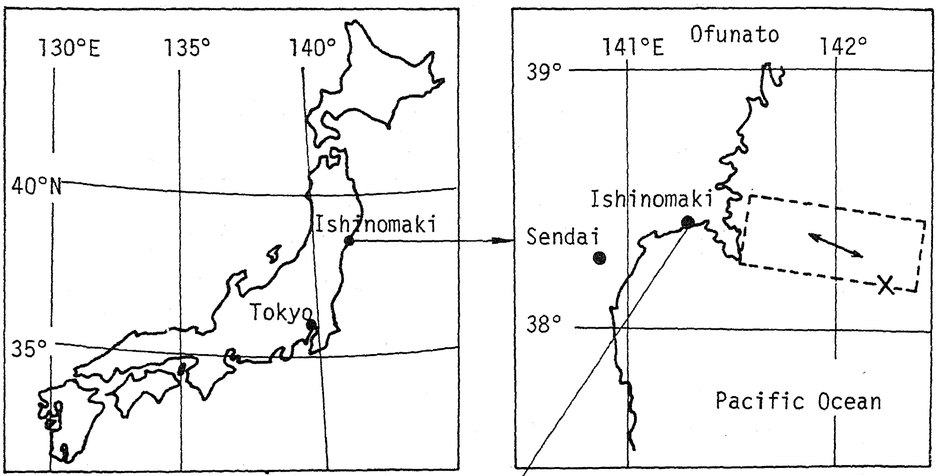
2) Kurata, E., et al., (1979): Strong-Motion Earthquake Records on the 1978 Miyagi-Ken-Oki Earthquake in Port Areas, Technical Note of the Port and Harbour Research Institute, No. 319.
3) Tsuchida, H., et al., (1979): The Damage to Port Structures by the 1978 Miyagi-Ken-Oki Earthquake, Technical Note of the Port and Harbour Research Institute, No.325.

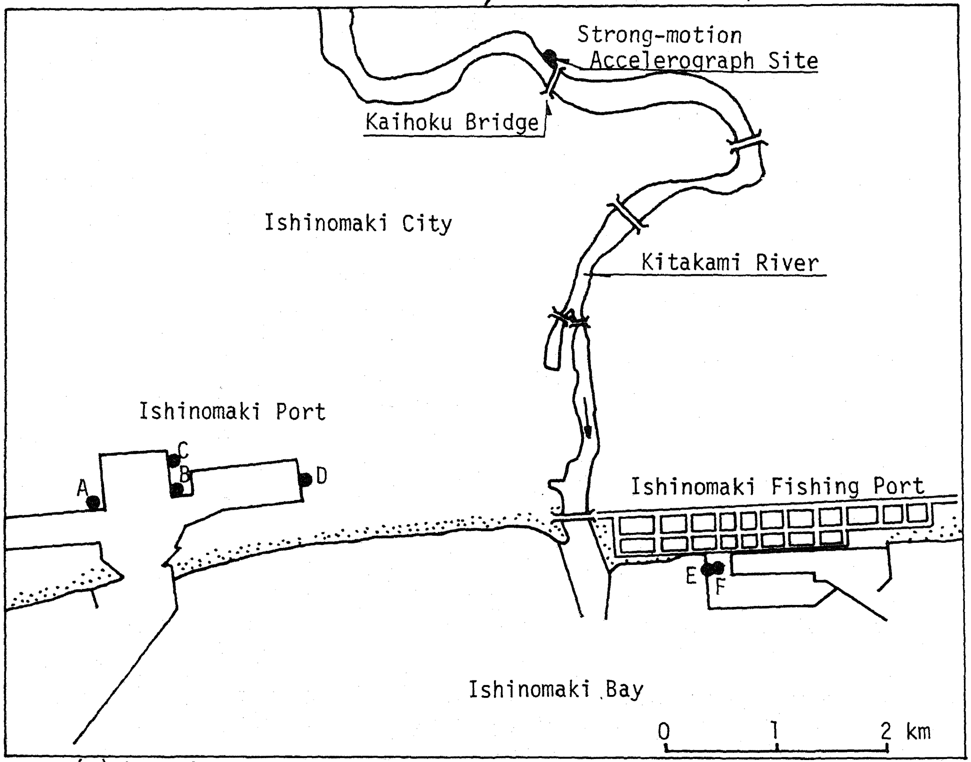
Table 1. Results of analysis

Site		A	B	C	D	E	F
Observed behaviour of ground		Liquefaction	Liquefaction	Non-liquefaction	Liquefaction	Non-liquefaction	Liquefaction
Results of analysis	Calculated surface acc. in gals	127	1o6	106	224	249	222
	Depth (m)	5.7	4.3	4.9	3.5	4.3	4.3
	N_{eq}	0.1	0.5	0	5.9	1.4	2.0
	N_ℓ	3.4	2.8	4	2.8	3.6	2.8
	N_{eq}/N_ℓ	0.0	0.2	0	2.1	0.4	0.7
	Depth (m)	7.3	6.3	6.9	12.0	8.3	7.3
	N_{eq}	0	0	0	6.9	12.6	7.1
	N_ℓ	4	2.5	4	3.0	3.6	2.5
	N_{eq}/N_ℓ	0	0	0	2.3	3.5	2.8
	Depth (m)	11.3	10.3	10.9			8.3
	N_{eq}	1.4	2.2	1.6			4.9
	N_ℓ	3	3	3			3
	N_{eq}/N_ℓ	0.5	0.7	0.5			1.6



(a) Location of Ishinomaki

(b) Locations of Ishinomaki and fault plane



(c) Locations of liquefied and non-liquefied sites, and location of strong-motion accelerograph site

Fig. 1 Locations of Ishinomaki, fault plane, and sites considered

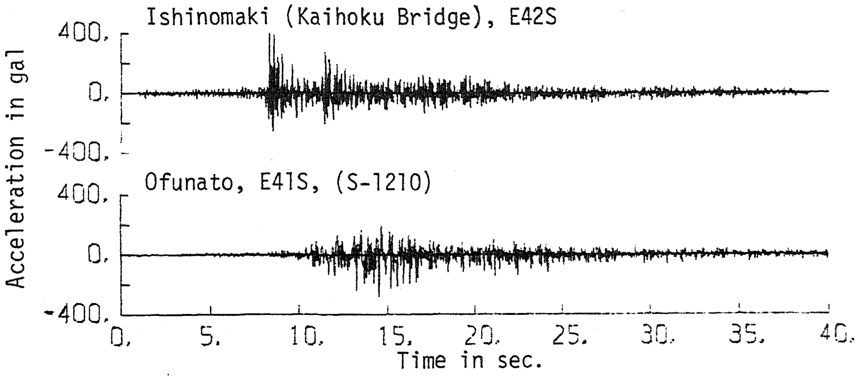


Fig. 2 Time histories of ground accelerations

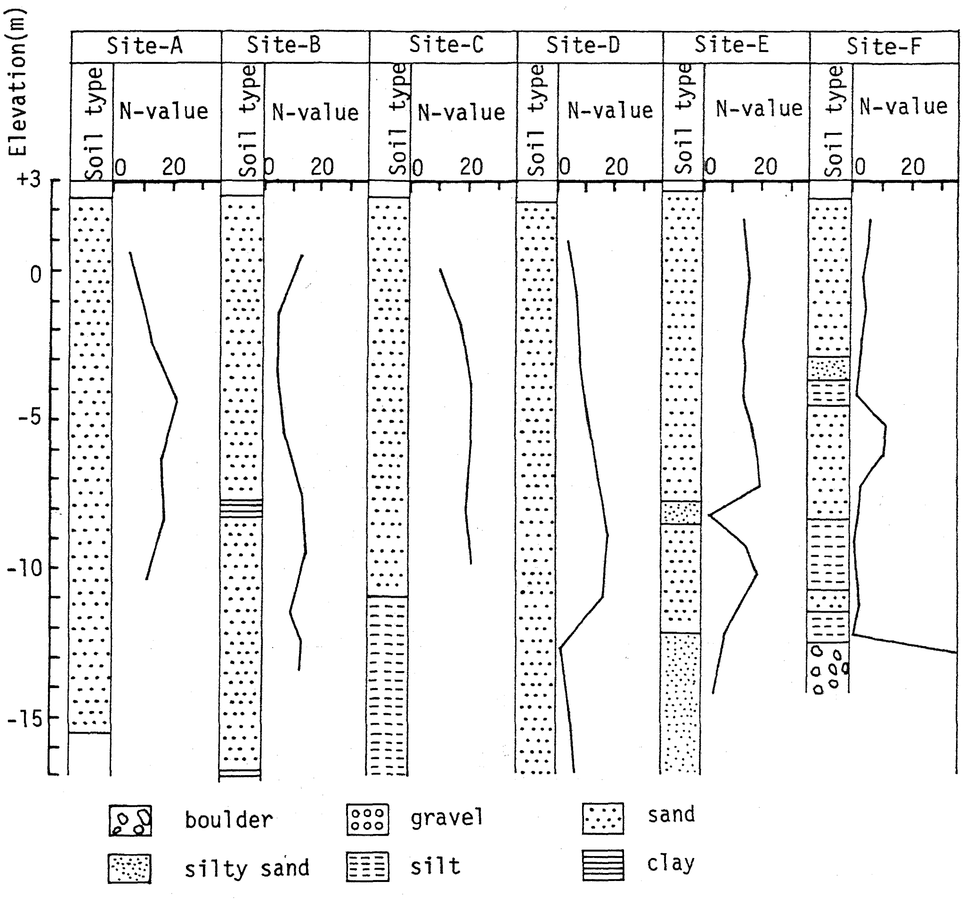


Fig. 3 Soil types and N-values of standard penetration test

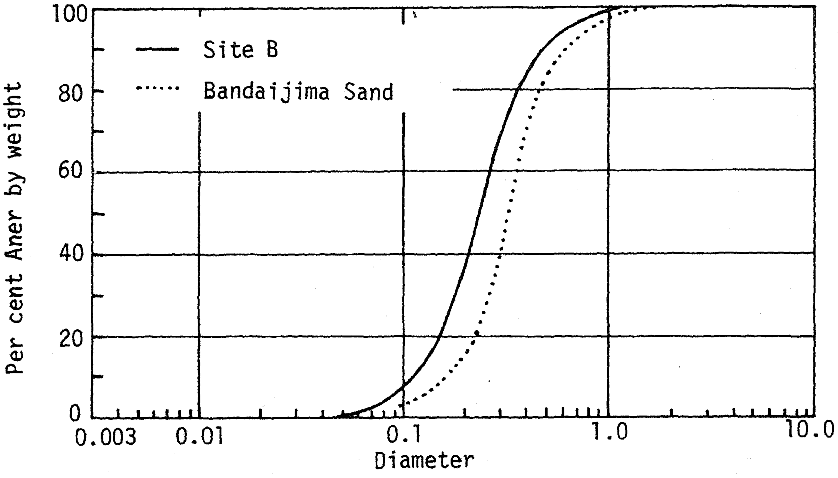


Fig. 4 Grain-size distribution curves of soils at the site B and Bandaijima

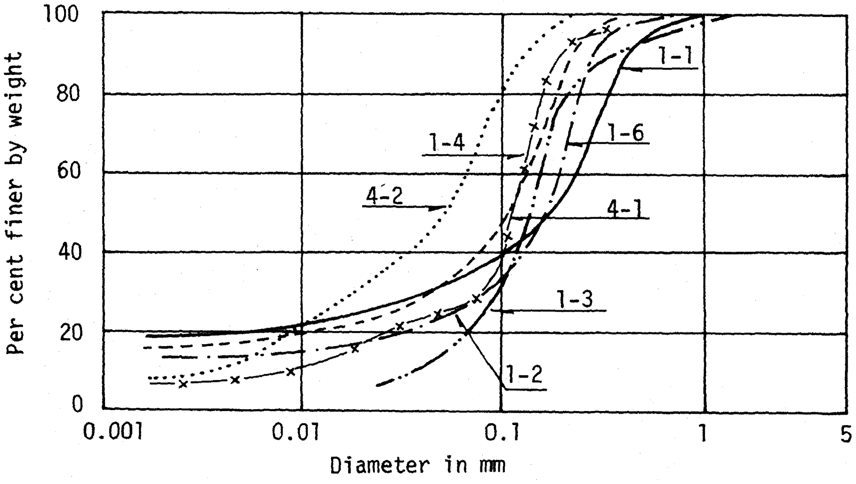


Fig. 5 Grain-size distribution curves of soils near the Sites E and F