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Earthquake Damage Done at Right Angles to Epicentral Direction

Makoto Nasu
Railway Technical Research Institute, Tokyo, Japan

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Makoto Nasu
Chief, Geotechnical Engineering Laboratory, Railway Technical Research Institute, Tokyo, Japan

SYNOPSYS : In order to make clear the structures of grounds which are liable to induce earthquake damage, the relations between seismic deformation of various objects and the structures of the grounds under them, and the intersectional angles between the epicentral direction and their longitudinal axes and between the epicentral direction and the deformational directions have been investigated on the basis of many examples of such damage. Various objects such as embankments on heterogeneous grounds, for example, grounds including inclined soft soil layer or made of soft soil layer with inclined bottom, or various objects straddling soft and hard grounds, are liable to be largely destroyed by earthquakes. Additionally, it seems that epicentral direction is associated with ground structure and so such objects are more liable to be damaged by earthquake. This paper cites many examples of earthquake damage in which the damage seems to be due to a predominant seismic force working approximately at right angles to the epicentral direction.

INTRODUCTION

Many examples of earthquake-induced damage to embankments, buildings, bridges etc. have been investigated referring many reports on earthquakes and damage due to them, and old and new topographic maps etc. The relation of earthquake-induced damage with ground structure and seismic motion direction has been made clear [1)-8)] This paper cites many examples of earthquake damage in which the damage was comparatively heavy and seems to be due to a predominant seismic force working approximately at right angles to the epicentral direction.[7)]

EARTHQUAKE-INDUCED DAMAGE EXAMPLES

The Big Kanto Earthquake(1923.9, M=7.9)

(a) The Fukuwara House in Hakone Gora
This house failed on a small valley on the north slope.[7)-10)] The ground seems to be made of a talus cone deposit. The flow line of this slope runs approximately at right angles to the epicentral direction, as shown in Fig. 1.

(b) The District near Tokyo station
In the Marunouchi Building and the Mitsukoshi-Mitsui Building, as shown in Fig. 2, the direction of the predominant seismic force to the former building coincided with that to the latter, and two had worked approximately at right angles to the epicentral direction and to two buried valleys lines of the Marunouchi buried valley and the Showa-Dori buried branch valley.[7)11)] In the Marunouchi district, the ground had been said to tend to shake in the east-west direction. Namely the ground was liable to shake in the direction that alluvium deposit became thicker. The direction coincided with the seismic motion direction and so in the comparatively large valley of the former the damage seems to have turned out heavier than in the latter valley.[6)19)]

The Fukui Earthquake (1948.6, M=7.1)

In the Daiwa Department Store building with different foundations, as shown in Fig. 3, the ground under the centr part with pile foundation which was deformed largely was a reclaimed land of an old moat which extended from east to west, and was softer than the ground under both outside parts of the building with spread foundation.[2)] Also, the old moat extended approximately at right angles to the epicentral direction as shown in Fig. 2.[6)7)19)]

The Niigata Earthquake (1964.6, M=7.5)

(a) The Niigata Station Building with pile foundation
As shown in Fig. 4, the soft ground bottom under the non-damaged A-block of this building was approximately horizontal. And B-block and C-block on the inclined bedrock tilted in the inclined direction of the bedrock[2)] . This inclined direction is approximately at right angles to the epicentral direction.[7)19)]

(b) The railway embankment between Deto and Nishime on the Uetsu Line
As shown in Fig. 5, this embankment soil flowed out 120m long approximately at right angles to the epicentral direction.[1)] This embankment straddled soft ground of peaty soil and hard ground, and this peaty layer and soil layers under it had been inclined in the flowing direction of the embankment soil. Also, the deformed zone of this embankment coincided with the existing zone of peaty soil.[6)7)]

The Tokachi-Oki Earthquake(1968.5, M=7.9)

(a) The Hakodate University
As shown in Fig. 6, the ground just beneath central part B close to the long side of main school building with spread foundation, which had collapsed extremely, was softer than right and left side grounds A, C, had inclined soil strata including peaty soil layers[2)5)] . Its span direction is approximately at right angles to the epicentral direction.[6)7)] They say that

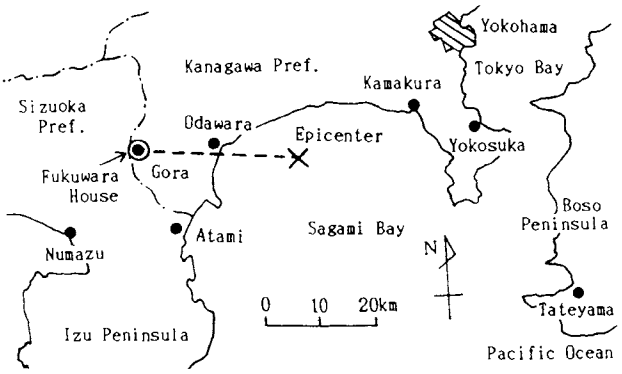


Fig.1 Damaged site of The Fukuwara House (1923 Big Kanto Earthquake)[8)-10)]

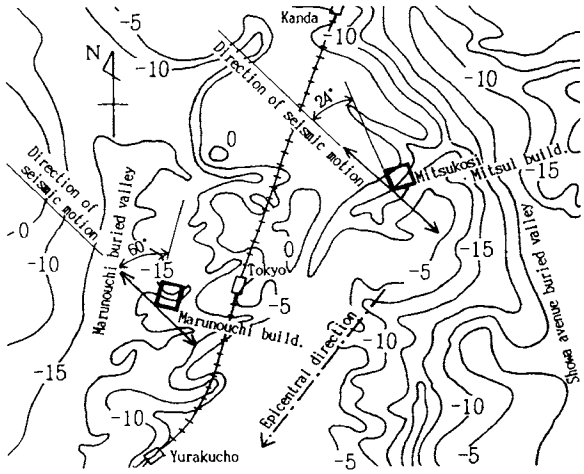


Fig.2 Equi-Depth Line (T.P., m) of Alluvium Bottom near the Tokyo Station (1923 Big Kanto Earthquake)[7) 8) 11)]

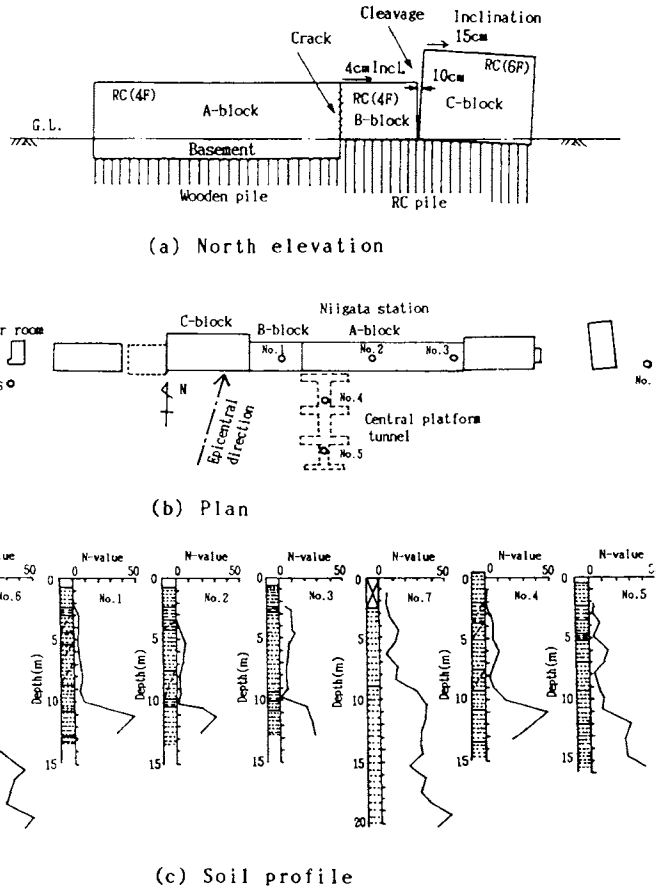


Fig.4 The Niigata Station (1964 Niigata Earthquake)[2) 7)]

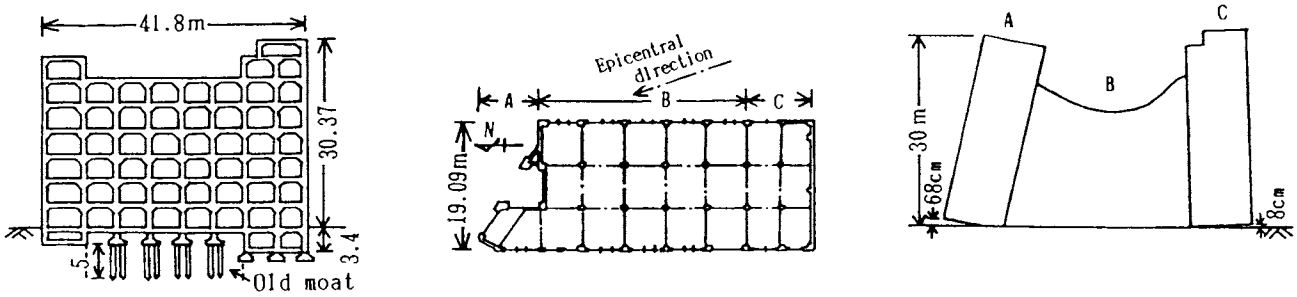


Fig.3 The Daiwa Department Store (1948 Fukui Earthquake)[2) 7)]

first this building shooke largely in the span directin approximately at right angles to the epicentral direction, and next did largely in the ridge direction. Nevertheless, the attached school building with spread foundation about 70m apart from the main building, was nearly intact on sandy loam ground.[12)]

(b) The Hachinohe City Hall

The ground under the northern part of the building with pile foundation which had been damaged by both this earthquake and Iwateken-Chubu earthquake in 1987, is a reclaimed land of an old moat, as shown in Fig. 7.[2)] Predominant seismic force direction in the former earthquake is estimated to have worked in the south-north direction with column crack etc., and also the top story the penthouse fell down in the southern direction of which the ground was good. The direction of the predominant seismic force in this case is approximately at right angles to the epicentral direction.[6) 7) 19)]

(c) The Hachinohe East Senior High School (with different foundations)

As shown in Fig. 8, the ground under the east part with pile foundation of A-building, which was heavily damaged, had the deposits of swamp

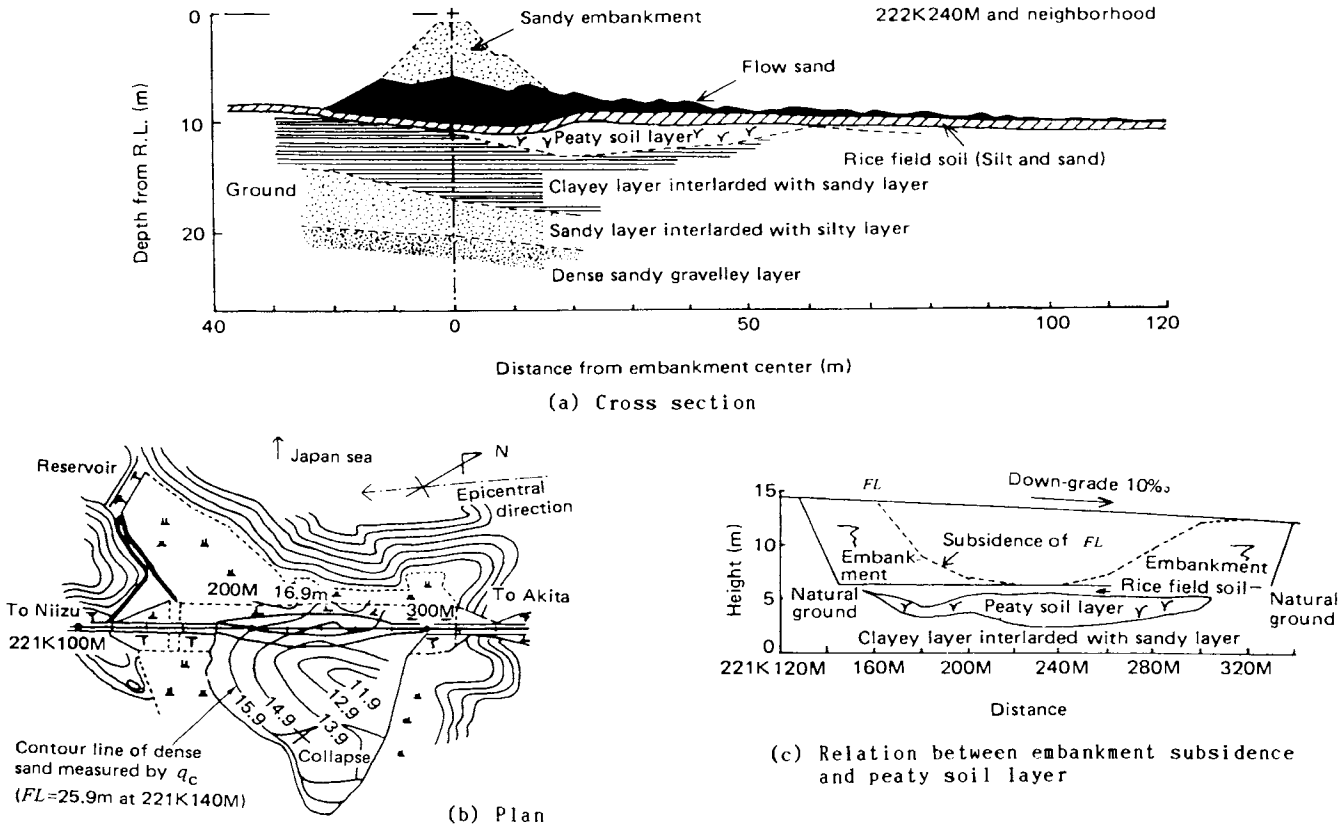


Fig.5 Railway Embankment in Deto (1964 Niigata Earthquake)[1)7)]

soil including peat or peaty soil layer.[2)] The predominant seismic force to the east part of the A-building had worked approximately at right angles to the epicentral direction, and the building was twisted from the original ground surface.[6)7)]

(d) In Hakodate, Muroran and Tomakomai Cities, the service pipe lines and distributing pipes of water supply system and water conveyance pipes of industrial waterworks, pipes buried approximately at right angles to the epicentral direction had been damaged mostly, as shown in Fig. 9.[13)]

The Miyagiken-Oki Earthquake(1978.6, M=7.4)

(a) The Nagamachi Koriyama Housing Complex
In the southern end of the reclaimed land of an old swamp which extends long in the north-south direction, as shown in Fig. 10, A-building with pile foundation was inclined in the span direction, namely to the south. This inclination had occurred in such a direction that the inclination bedrock surface becomes shallow[2)], and it was at right angles to the epicentral direction.[6)7)19)]

(b) The Maruyoshi Industrial Building
In this building with pile foundation, piles in one foundation had various lengths as shown in Fig. 11.[2)] The ridge direction approximately follows the epicentral direction, and especially the inclination of the building is larger in the span direction, being approximately at right angles to the epicentral direction, than in the ridge direction.[6)7)] Also, the inclination of the span direction is such that piles become short and the bedrock surface does shallow.[19)]

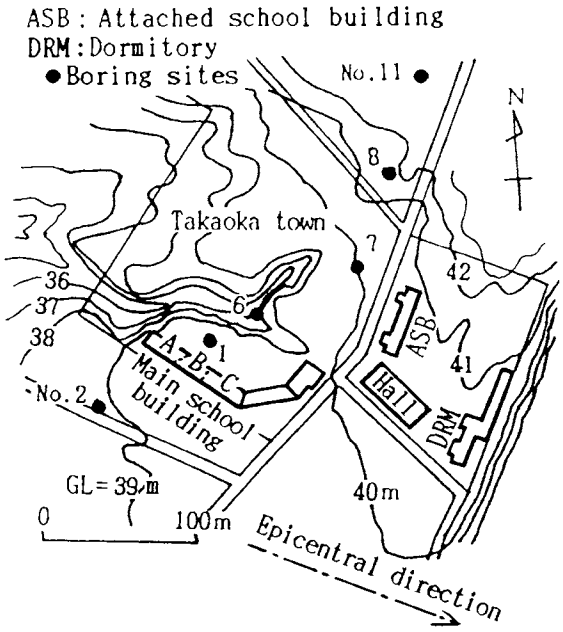
(c) The Tohoku University Building
As shown in Fig. 12, the ground underlying this building had shown a small valley type topography on a terrace, and ridge direction was approximately parallel to valley axis. This building had been constructed straddling the valley, and shear cracks had occurred both in the east gable and the west gable.[2)] This ridge direction approximately coincides with the the epicentral direction, and a predominant seismic force works approximately at right angles to the epicentral direction.[6)7)]

The Urakawa-Oki Earthquake (1982.3, M=7.1)

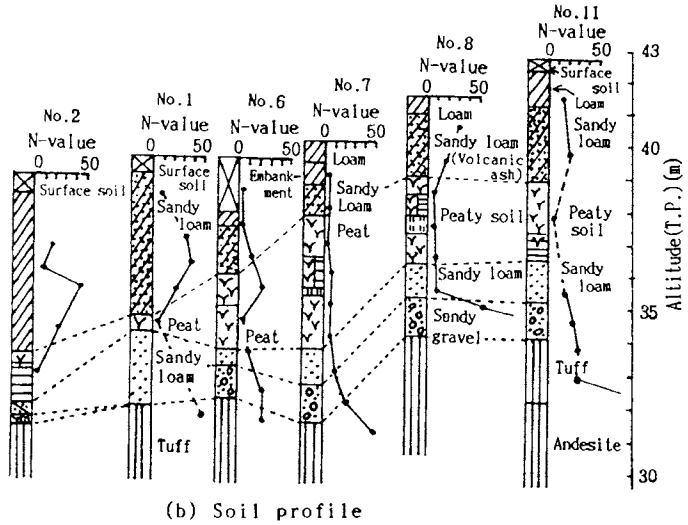
The Sizunai Bridge on the national highway with caisson foundation was damaged by this earthquake. X-type shear cracks in some piers occurred oblique to the bridge axis. Predominant seismic force had worked at right angles to the epicentral direction.[3)19)]

The Nipponkai-Chubu Earthquake(1983.5, M=7.7)

(a) The railway embankment between Koikawa and Kado on the Ou Line
This embankment failed on the ground in which the bottom of the soft soil stratum including a thick peaty layer greatly tilted, as shown in Fig. 13[1)] . Considering the damaged zone and the ground structure, it is estimated that the soft soil stratum bottom near 334K680M inclined



(a) Plan



(b) Soil profile

Fig.6 The Hakodate University (1968 Tokachi-Oki Earthquake)[2) 12)]

toward embankment axis and toward the starting point rather than the soft soil stratum bottom inclined at right angles to embankment axis influenced the failure first,[6) 7)] whereas a neighboring 334K720M embankment underlaid with very soft and almost horizontal soil layer did not subside nor was it deformed.[1)]

(b) The Kansuke Reservoir Earth Dam

An embankment near the left shore of which the up-stream side subsided especially largely, crossed the valley line that approximately coincided with the epicentral direction, and the inclination of both side slopes of its valley was comparatively steep, as shown in Fig. 14.[1)] Also, an embankment on hard ground near the right shore had deformed in the inclined direction of the embankment bottom and approximately at right angles to the epicentral direction.[1) 6) 7)]

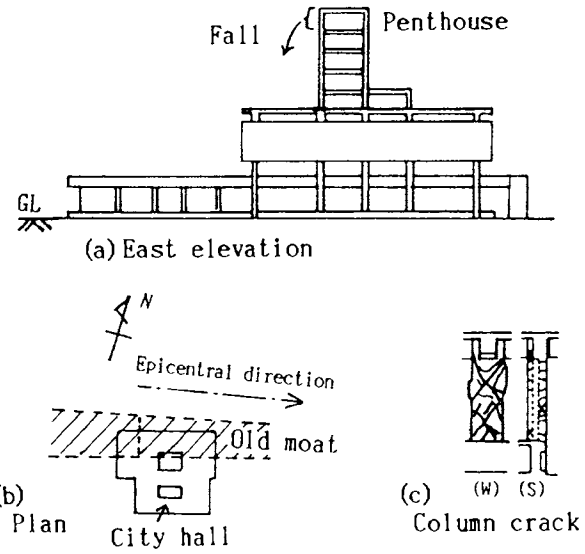
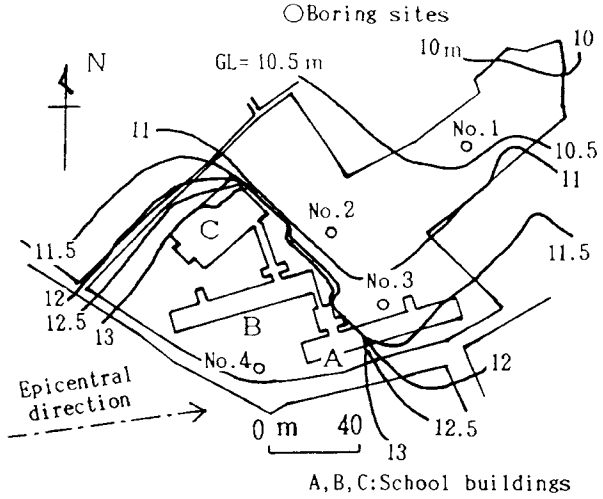
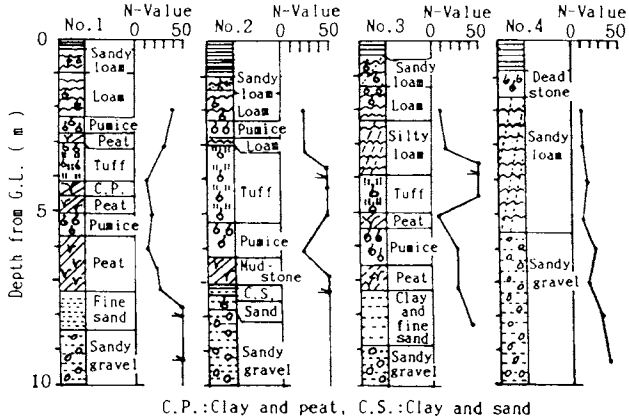


Fig.7 The Hachinohe City Hall (1968 Tokachi-Oki Earthquake)[2]



(a) Plan



(b) Soil profile

Fig.8 The Hachinohe East Senior High School (1968 Tokachi-Oki Earthquake)[2) 7)]

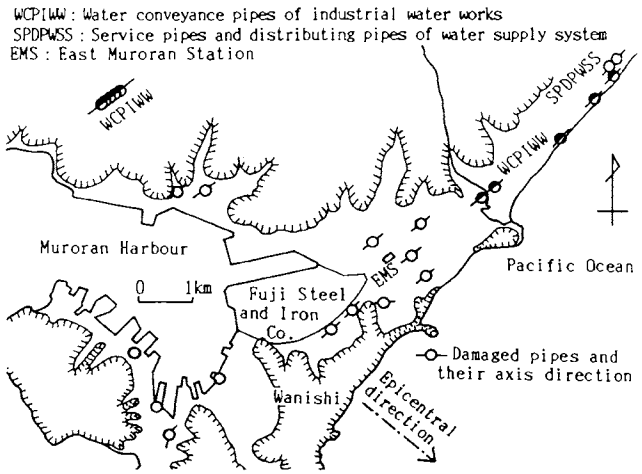


Fig.9 Main Damage of Pipe Lines of Industrial Water Works and Water Supply System in Muroran City (1968 Tokachi-Oki Earthquake)[13]

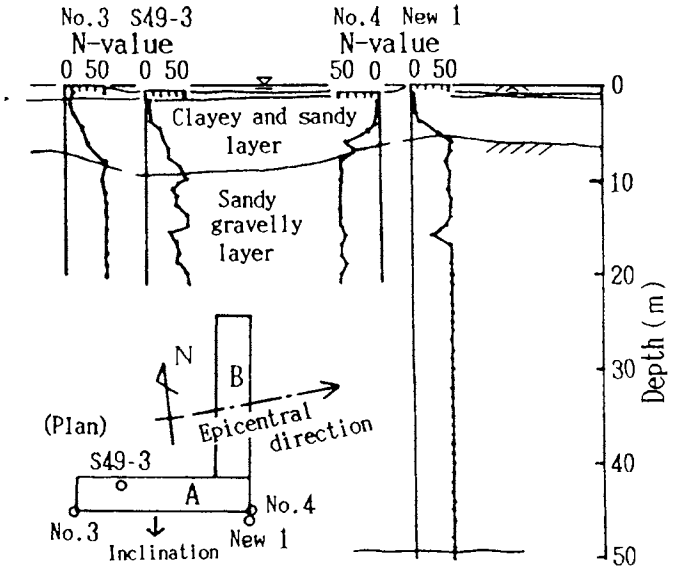


Fig.10 Ground of the Nagamachi Koriyama Housing Complex (1978 Miyagiken-Oki Eartquake)[2)7)]

The Chibaken-Toho-Oki Earthquake (1987.12 , M=6.7)

The ridge direction of apartment buildings in one prefectural housing complex with pile foundation of which cracks occurred on neighboring grounds, and the ridge direction of many private houses of which roofing tiles had been damaged nearly coincided with the epicentral direction, and these buildings or houses shook largely approximately at right angles to the epicentral direction. The axis of the valley plain at this site coincided approximately with the epicentral direction.[6)7)]

Additionally, natural slopes in Nakagi(1974) and Otaki Village Matukoshi(1984, see Fig. 15), embankments in Kotobukiyama(1978) and the Mochikoshi mine(1987) have collapsed exactly or approximately at right angles to the epicentral direction.[6)7)14)]

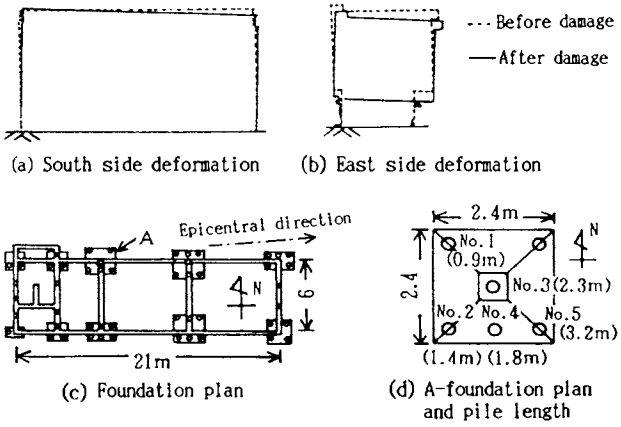


Fig.11 The Maruyoshi Building (1978 Miyagiken-Oki Earthquake)[2)7)]

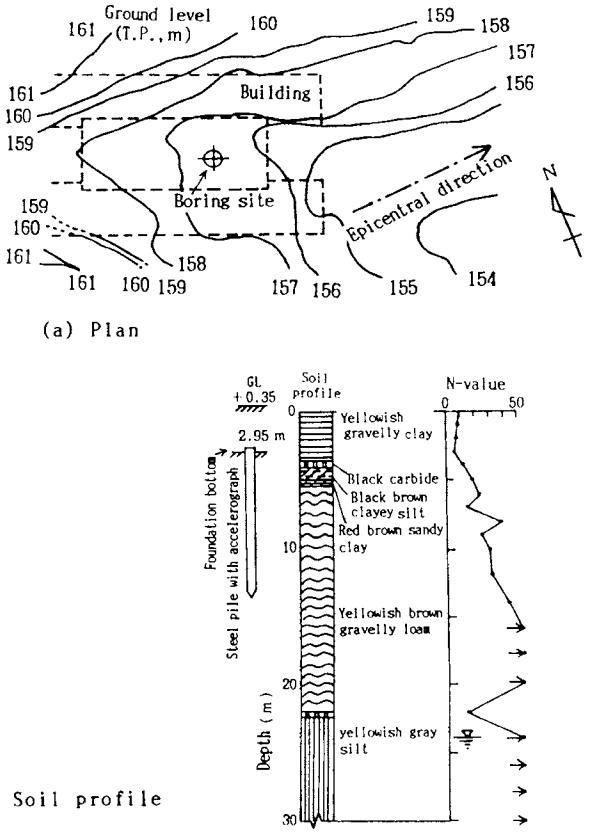


Fig.12 The Tohoku University Building (1978 Miyagiken-Oki Earthquake)[2)7)]

The Loma Prieta Earthquake(1989.10, M=7.1)

The bridge axis direction of the San Francisco-Oakland Bay Bridge in which upper and lower decks fell down, and the directions at the right angles to the bridge axis of the collapsed Cypress viaduct, of the Embarcadero Viaduct of which piers were damaged, and of the Struve Slough Bridge of which girders and piers were damaged, were commonly approximately at right angles to the epicentral direction, as shown in Fig. 16.[7)15)-19)] Namely, the predominant

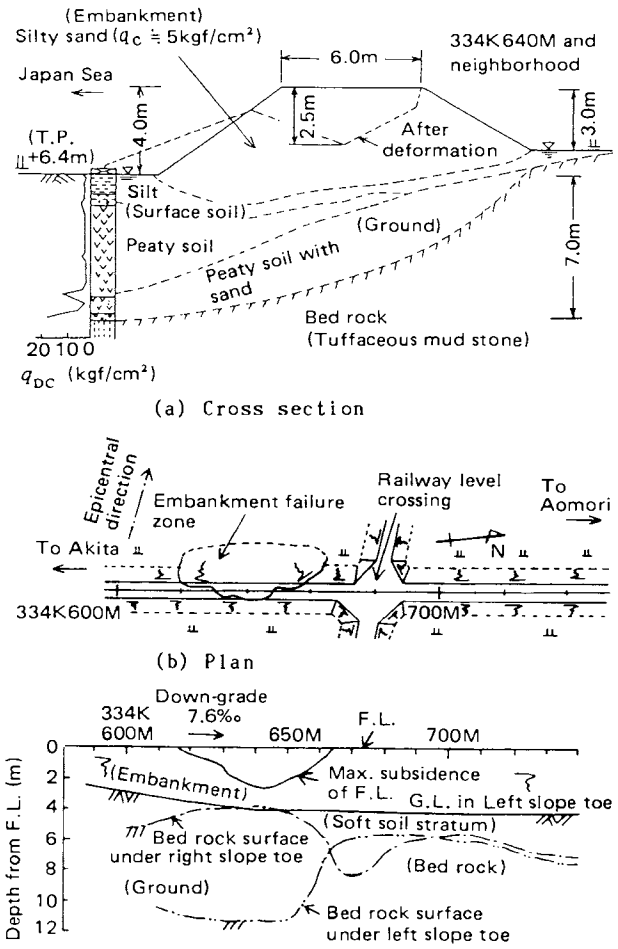


Fig.13 Railway embankment in Koikawa (1983 Nipponkai-Chubu Earthquake)[1)7)]

seismic force had worked at right angles to the epicentral direction, and this direction was at right angles to the Bay axis.[7)18)] The ground shook largely approximately at right angles to the epicentral direction and approximately at right angles to the valley axis,[18)] and the phenomenon was the same as occurred in Tokyo Marunouchi district during the Big Kanto Earthquake in 1923 and so on in Japan.[7)19)]

(a) Because the damaged Bay Bridge had been constructed straddling both thick and thin parts of soft Bay Mud in the bridge axis direction as shown in Fig. 17[15)-17)19)] and a differential displacement occurred largely in its direction, the bridge decks are concidered to have fallen down.[3)] Moreover, the Bay Bridge moved largely at right angles to the bridge axis,[17)] namely in the radial direction of the equi-depth line of the Bay Mud. This can be expected from Fig. 15 showing the equi-depth line of the Bay Mud base.[3)16)]

In Japan, also, many earthquake-induced damages have occurred in objects straddling thin part and thick part of soft soil layer or in objects on heterogeneous ground. For example, the Yachiyo Bridge(1943), the Shinano-gawa Bridge, the Sasaguchi Overbridge, the Showa-Ohashi

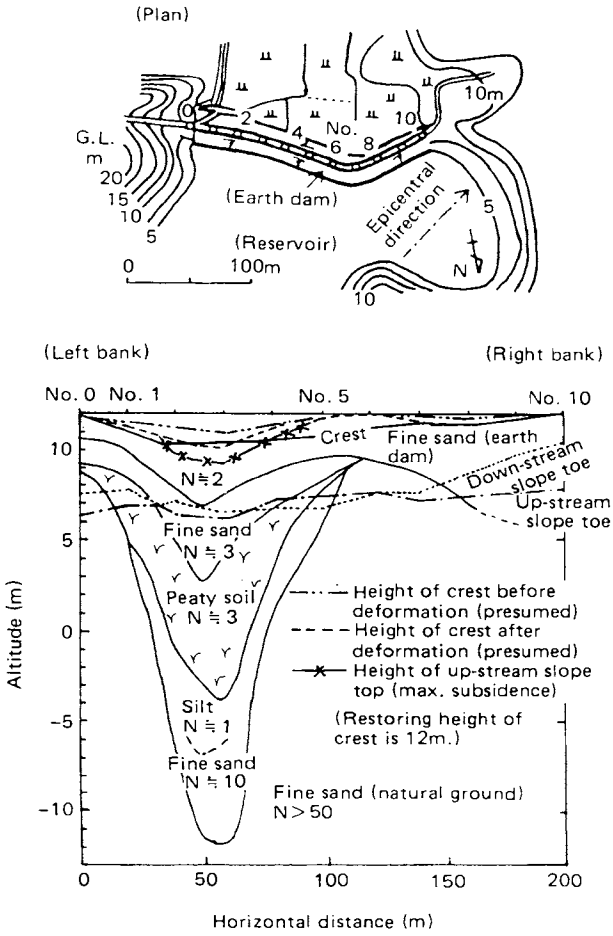
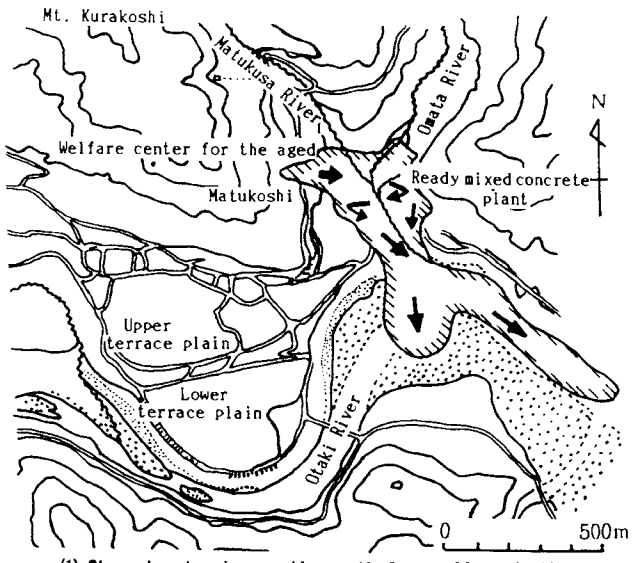


Fig.14 Relationship between earth dam subsidence and ground condition in Kansuke reservoir (1983 Nipponkai-Chubu Earthquake, revised original figure)[1)7)]



(1) The epicenter is exactly north from collapsed site.
(2) Arrows show the flowing direction of collapsed soil.

Fig.15 Slope Collapse in Otaki Village Matukoshi (1984 Naganoken-Seibu Earthquake)[7)14)]

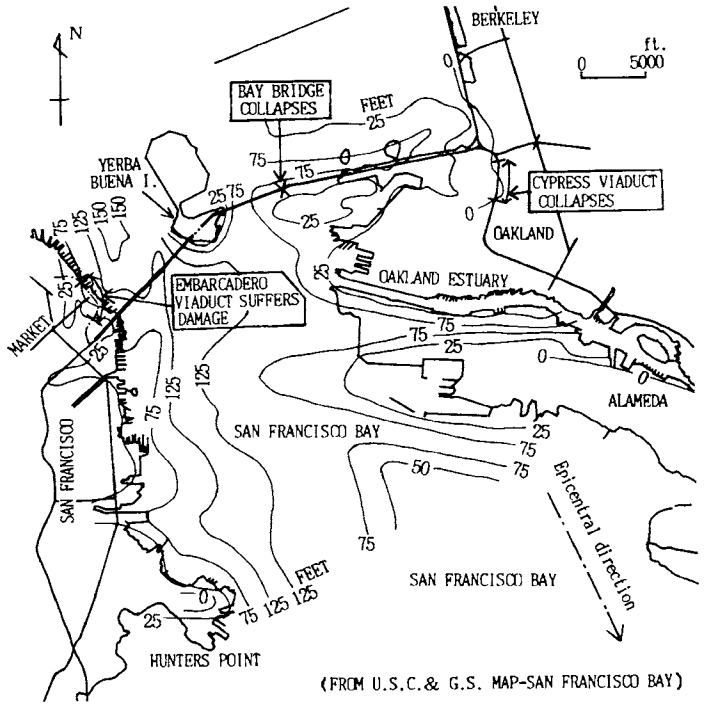


Fig.16 Equi-depth line of Bay Mud base in San Francisco Bay (1989 Loma Prieta Earthquake)[7)15)-17)]

Bridge (see Fig. 18),[20)] the Yachiyo Bridge (1964, commonly), the Kin-o Bridge(1978) and so on were deformed in the bridge axis direction. Many of them had been constructed straddling thin part and thick part of soft soil layer,[1)-3)6)7)] and their grounds were similar to the Bay Bridge ground.[19)]

(b) Both the Embarcadero Viaduct where shear cracks have occurred in some piers at right angles to the bridge axis and the remarkably collapsed Cypress Viaduct has crossed the buried valley in the neighborhood of its exit to the Bay. As shown in Fig. 16, the bottom of the soft Bay Mud overlying these buried valleys was inclined toward the Bay.[3)16)17)] Especially, the ground of the zone where the Cypress Viaduct collapsed remarkably was a soft ground reclaimed from the swamp, and the most of it seems to be old river beds or old lagoons, and there is included a very soft clayey or silty layer etc. within the ground.[17)19)]

Since the Arakawa Bridge on the Tohoku Line(1923), the national highway Shizunai Bridge (1982), the Mizubuka Viaduct(1987) etc. in Japan had been deformed at the same right angles to the bridge axis as the Cypress Viaduct etc., soft soil layer under the former three bridges might have been inclined at right angles to the bridge axis.[6)19)]

Also, these deformation direction coincided with the directions of the soil soft layer bottom

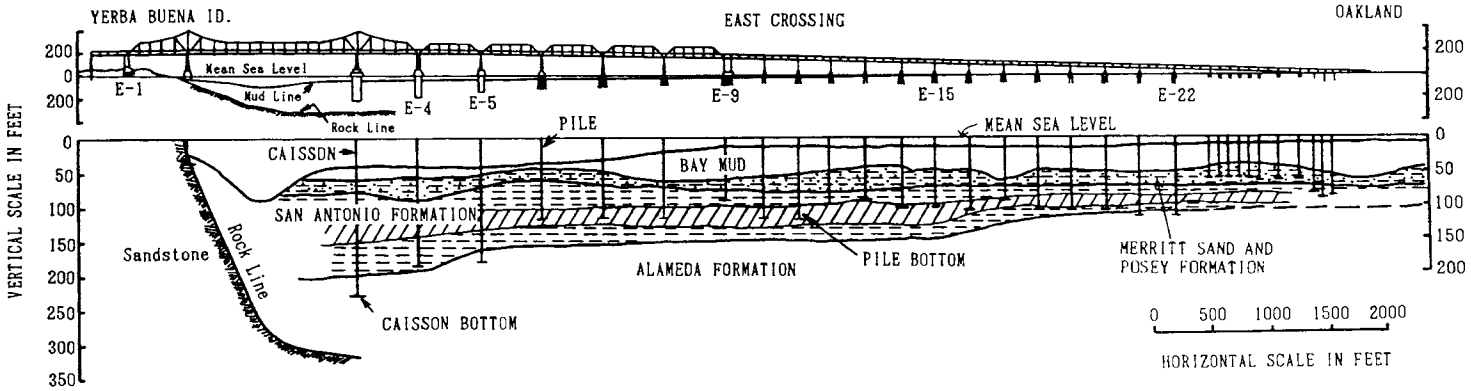


Fig.17 The San Francisco-Oakland Bay Bridge (revised original figure)[3)15)16)19)]

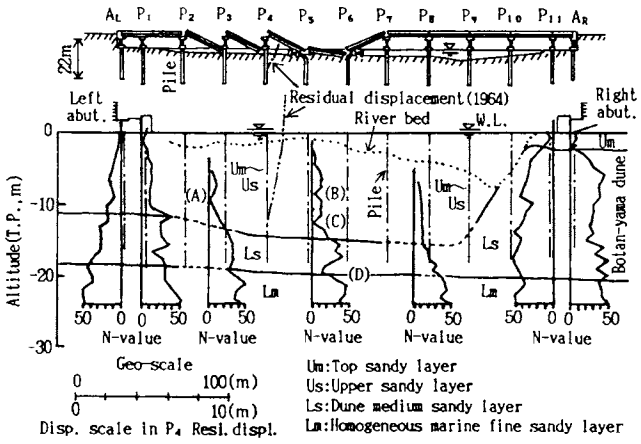


Fig.18 The Showa-Ohashi Bridge (1964 Niigata Earthquake)[3)20)]

becoming shallow. Similarly the Nagamachi Koriyama Housing Complex Building, the Maruyoshi Building(1978, both), the Hachinohe City Hall(1968) etc. in Japan were inclined especially largely in the direction of the soft soil layer bottom becoming shallow.[2)7)]

(c) In the central part of the Struve Slough Bridge with pile foundation, a predominant seismic force worked approximately at right angles to the bridge axis, and girders fell down.[17)] The girders moved to the east and its piles moved to the west. The front and rear abutments were constructed on hard ground and many piers among them stood on a marshy ground consisting of mainly organic soil.[17)19)] Because the southbound bridge was deformed more heavily than the northbound bridge, and in the neighborhood of the deformation occurrence place the ground was hollowed in the valley shape, it is estimated that the hard ground surface under the soft soil layer becomes

suddenly deep toward the west according to the deformation extent, and the soft soil layer becomes thick toward the west.[19] Also, the girders are estimated to have moved to the west to which the soft soil layer becomes thin.

Moreover, because the deformation status of the Nagaya bridge(1948) and the Sakae bridge(1964) in Japan was similar to that of the Struve Slough Bridge, the structure of grounds under these three bridges might have been similar to each other.[3)19)] Also, the Struve Slough Bridge has been damaged on a ground structure like that of the Hakodate University Building(1968) and the Nagamachi Koriyama Housing Complex Building(1978).[2)19)]

SOIL STRUCTURE OF GROUND UNDER EARTHQUAKE-DAMAGED OBJECTS

In Japan, in grounds whose subsoil layers include soil layers(A ～D in Fig. 18) of less strength than about 15 in N-value like the Showa-Ohashi Bridge(1964)[20] or the Hakodate University(1968), earthquake-induced damage has occurred in many spots, and most of the grounds had inclined sedimentary structures.[1)-3)19)] Also, the grounds of the Marina district, of the district along the Market Street and of the South Market district in San Francisco where various damages occurred during the Loma Prieta Earthquake(1989), have included clayey soils with soft peat etc., or the soft Bay Mud.[17)19)]

Consequently, the author considers that, for example, a remarkable damage due to earthquake in the ground having an inclined soft soil layer occurs by a similar phenomenon to a landslide.

CONCLUSIONS

Many examples of earthquake-induced damage have been investigated in which the predominant seismic force seems to have worked at right angles to the epicentral direction. Grounds underlying them involve a soft soil layer which is inclined or has a thickness varying in damaged direction, namely at right angles to the epicentral direction. It seems that a remarkable damage has to have occurred because the working direction of the seismic force coincided with the varying direction of the soil layer thickness. Moreover, it seems that the farther the objects are from the epicenter, the more remarkable becomes the aforementioned tendency.

In this way, because both the ground structure and seismic force direction have very much to do with the occurrence of the earthquake-induced damage, it is necessary to fully study both of them in order to prevent or reduce such damage. Also, earthquake-resistant design must be selectively adopted depending on the objects being liable to be earthquake-deformed or not.

Finally, the auther is convinced that the deformation of objects due to earthquake faithfully reflects the ground status.

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