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A study on structures of grounds liable to induce earthquake damage

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ABSTRACT : The structures of grounds on which various objects are liable to be damaged by earthquakes have been studied, in order to clarify occurring mechanism of earthquake damage to these objects, to develop earthquake-proof measures and to select appropriate sites for providing such measures.

1 INTRODUCTION

Many examples of earthquake-induced damage have been investigated mainly on the basis of many documents, for examples, reports on various earthquakes, old and new topographic maps, and soil investigating reports and so on. Especially, ground structures of occurring sites of some earthquake damage which was comparatively heavy have been investigated in detail.

2 SOME EXAMPLES OF EARTHQUAKE DAMAGE

2.1 Embankments[1)]

(1) In the Tokachi-oki earthquake of 1968, a section between Mukaiyama and Misawa on the Tohoku Line suffered an embankment failure which extended to the track. In another case of the same section, a slope flow-out occurred on a newly-constructed embankment. Embankments in these cases are located near a plateau on a valley plain. Seriously-damaged sites of the former case are located at the intersection of the embankment with a branch valley, coinciding with the one which occurred at the time of a storm rainfall disaster in September 1967.

Comparing the damages at these sites, with the damage due to the Tokachi-oki earthquake, it has been made clear that at a location with a larger failure all of the newly-constructed embankments and their subbanks come over a soft ground with a single peaty layer at the location of steeply-inclined bed rock surface, where embankment failures occurred in the inclined direction of bed rock surface. Furthermore, though the ground which suffered a slope flow-out of the new embankment consists of soft ground including a peaty layer, only the slope of the new embankment was located at the steeply-inclined portion of bed rock surface. At the location where no deformation was generated, the bed rock surface undelying soft ground of peaty soil is approximately horizontal.

(2) Between Otsutomo and Isibumi on the Tohoku Line in the same earthquake, large cracks ran from slope top to slope surface on the left side of a railway embankment as shown in Fig. 1. The embankment of this site stretching over both an old river bed and natural ground moved as it had turned to the old river bed side, causing the cracks.

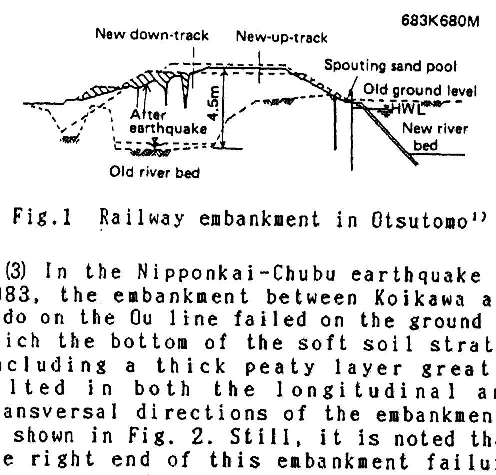

Fig.1 Railway embankment in Otsutomo[1)]

(3) In the Nipponkai-Chubu earthquake of 1983, the embankment between Koikawa and Kado on the Ou line failed on the ground in which the bottom of the soft soil stratum including a thick peaty layer greatly tilted in both the longitudinal and transversal directions of the embankment, as shown in Fig. 2. Still, it is noted that the right end of this embankment failure zone agrees with the right end of the zone of a very soft peaty soil.

A neighboring embankment underlaid with a very soft and almost horizontal soil stratum did not subside nor was deformed. Furthermore, the embankment strength around this site is fairly low, that is q_c = 5 kgf/cm^2(≒0.5 MPa), regardless of failed or

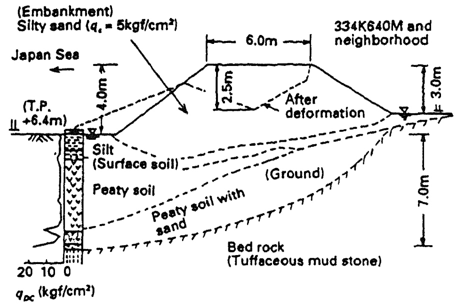

Fig.2 Railway embankment in Koikawa[1)]

not.

2.2 Buildings[2)]

(1) In the Fukui earthquake of 1948, the Daiwa department store building with different foundations collapsed. The ground under the central part with pile foundations which settled and collapsed largely was the reclaimed land of an old moat which extended from east to west, and was softer than the grounds under both outside parts of the building with spread foundations. Also, the old moat extended approximately at right angles to the epicentral direction.

(2) In the Niigata earthquake of 1964, the soft sandy ground bottom under the non-damaged east A-block in the Niigata station building with pile foundations, was approximately horizontal. Both the central B-block and the west C-block on an inclined dense sandy layer surface tilted in their inclined direction from the east to the west. The distribution of pile lengths under the building corresponds with the inclination of this dense sandy layer surface.

Furthermore, a thin clayey layer with extremely small N-values near G.L.-10m in the ground was found to be inclined in the direction from the east to the west under the A-block. Consequently, sandy layers on this clayey layer are considered to have slided in that direction.

(3) The Hachinohe City Hall building was damaged heavily by the Tokachi-Oki earthquake of 1968. Moreover, its window glasses were mainly broken in the Iwateken-Chubu earthquake of 1987. The ground under the northern half part of it is the reclaimed land of an old moat, and the ground under the southern one is an old natural ground. In the former earthquake, predominant seismic force direction is estimated to have worked in the south-north direction from diagonal and horizontal cracks in columns etc., and the top story of the penthouse fell down in the direction of southern part under which the ground was firm. And long cracks in the floors ran in the east-west direction.

(4) In the Miyagiken-Oki earthquake of 1978, the collapsed building of the Maruyoshi industrial Co. Ltd. had piles of various lengths even in one foundation as shown in Fig. 3, and the ratio of the max. length of them to the min. one was about 3.5. At this site the depth of the bedrock varied suddenly. Especially the inclination of the building was larger in the span direction than in the ridge direction. The span direction was inclined in the direction in which piles became shorter and the soft soil layer thinner. The ridge direction is inclined in the direction in which the soft soil layer became thicker.

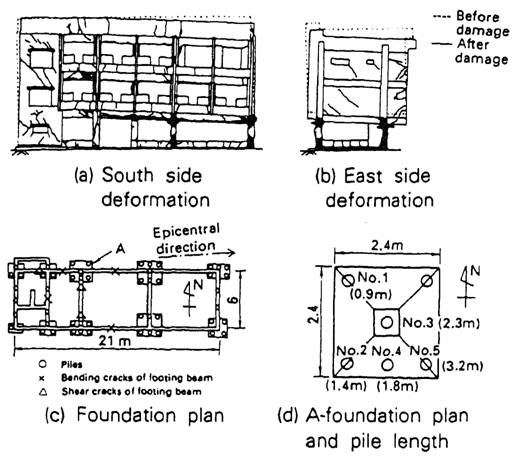

Fig.3 The Maruyoshi building[2)]

2.3 Bridges[3)]

(1) In the Loma Prieta earthquake of 1989, the bridge axis direction of the San Francisco-Oakland Bay bridge in which upper and lower decks fell down, and the directions at 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 all approximately at right angles to the epicentral direction, and this direction was at right angles to the Bay axis.

Because the damaged Bay Bridge had been constructed straddling both thick and thin parts of the soft Bay Mud in the bridge axis direction as shown in Fig. 4 and a seismic differential displacement occurred largely in its direction, the bridge decks on the pier E-9 are considered to have fallen down. The soft Bay Mud thickness changes at the site of this pier. Moreover, the Bay Bridge moved largely at right angles to the bridge axis, namely in the radial direction of the equi-depth lines of the Bay

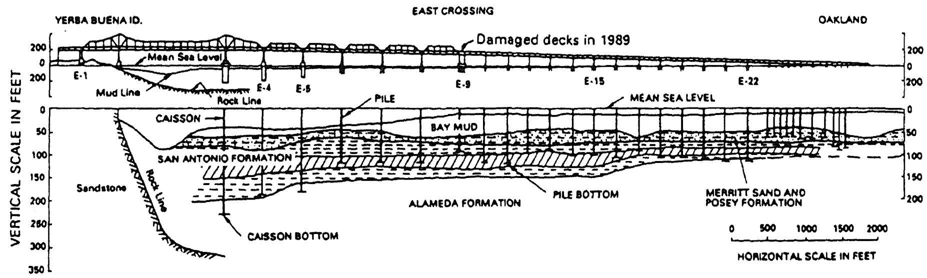

Fig.4 The San Francisco-Oakland bay bridge (revised original figure)[3]

Mud. This can be expected from the equi-depth line map of the Bay Mud base.

(2) In Japan, many earthquake-induced damages have occurred in bridges straddling thin part and thick part of soft soil layer or in objects on heterogeneous ground. These grounds were similar to the Bay Bridge ground. For example, the Showa-Ohashi bridge was deformed in the bridge axis direction. The sandy ground under it includes tilting sedimentary structures, and especially very soft clayey or peaty soil layers with very small N-values exist only within the ground under the fall zone of girders

(3) Both the Embarcadero viaduct where shear cracks have occurred in some piers at right angles to the bridge axis in 1989 and the remarkably collapsed Cypress viaduct have crossed the buried valley in the neighborhood of its exit to the Bay. The bottom of the soft Bay Mud overlying these buried valleys was inclined toward the Bay. Especially, the ground of the zone where the Cypress viaduct collapsed remarkably was a soft ground reclaimed from swamps, and the most part of it seems to be old river beds or old lagoons, and the ground includes a very soft clayey or silty layer. Also, the deforming directions of the Cypress viaduct etc. seem to have coincided with the directions of the soft soil layer bottom becoming shallow.

(4) In the central part of the Struve Slough bridge with pile bent foundation, the girders fell down approximately at right angles to the bridge axis in 1989. And the girders moved to the east and theirits 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.

Because the southbound bridge was deformed more heavily than the northbound bridge, and in the neighborhood of the deformation the ground was hollowed in a valley shape, it is estimated that the hard ground surface under the soft soil layer becomes suddenly deep toward the west depending on the deformed extent of both bridges, and the soft soil layer becomes thick toward the west. Also, the girders are estimated to have moved to the east toward which the soft soil layer becomes thin. Moreover, because the deformation status of the Nagaya bridge(1948) etc. in Japan was similar to that of the Struve Slough bridge, the structure of grounds under their bridges might have been similar to each other. Also, the Struve Slough bridge has been damaged on a ground structure like that of the Hakodate University building(1968) etc.

(5) Many bridges of the Shizunai bridge, the Mizubuka viaduct etc. in Japan had been deformed similarly at right angles to the bridge axis to the Cypress Viaduct etc. In the grounds under these bridges, very soft clayey soil layers exist under dense sandy soil layers. In one case the clayey soil layers are thin and inclined. In another case the clayey soil layers are thick and their bottom is inclined. The same structures of grounds as those are found in the grounds under earthquake-damaged buildings.

For example, the Sizunai bridge on the national highway with caisson foundation was damaged by the Urakawa-Oki earthquake of 1982. X-type shear cracks in some piers of the bridge occurred oblique to the bridge axis. In this ground very soft clayey soil layers lie comparatively thin under a dense sandy layer. The Mizubuka viaduct has crossed a buried branch valley in the neighborhood of its exit to a larger buried valley. In the buried branch valley, a dense sandy layer overlying a thick very soft clayey stratum has thick and thin parts. Only piers on the thick sandy layer were damaged by the Chibaken-Toho-Oki earthquake of 1987.

3 RESULTS

Main results of the abovementioned investigation are summarized as follows[1)-3)]:

(1) Various objects are very little damaged by earthquakes, when grounds under them are approximately horizontally-stratified not only in soft grounds but also in hard grounds.

(2) Various objects are liable to be

deformed by earthquakes on grounds where the surface of hard soil layer underlying soft soil layer is inclined, and when these objects straddle both soft ground and hard ground, as shown in Fig. 5. In the latter case, they are liable to be deformed remarkably by earthquakes.

(3) The deformation of objects occurs in the inclined direction of the bottom of soft soil layers.

(4) Above-mentioned soft soil layers consist mainly of soils like peat or peaty soil, soft clayey soil, filling or reclamation and so on.

(5) In upside-down type grounds whose subsoil layers have very soft clayey or peaty soil layers with very small N-values under hard soil layers, earthquake-induced damage has occurred often, and most of the grounds included tilting sedimentary structures.

4 CONCLUSIONS

It has become clear that various objects on uneven grounds, for example, on grounds with inclined soft soil layers are liable to be damaged by earthquakes. Such grounds have structures which are discontinuously dynamical and static. It is mainly supported that many of various objects have been destroyed because large differential lateral and/or vertical displacements depending on the uneven thickness of soft soil layers happened to the grounds, and it is speculated that an earthquake-damage in the ground having inclined thin soft soil layers is caused by a landslide-like ground movement. And the auther is convinced that their deformed states reflect faithfully the condition of grounds[3)]

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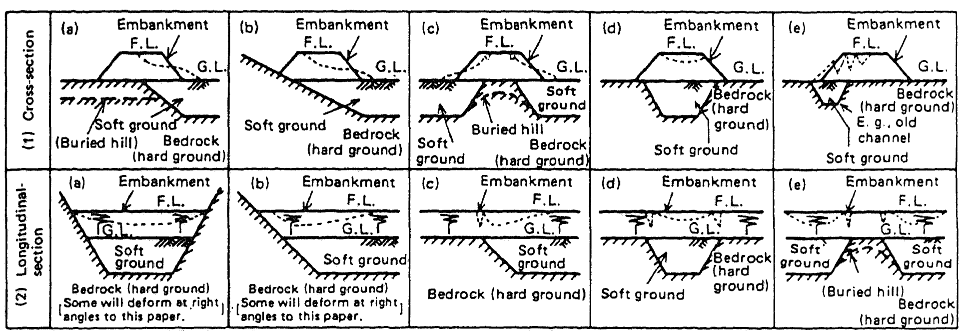
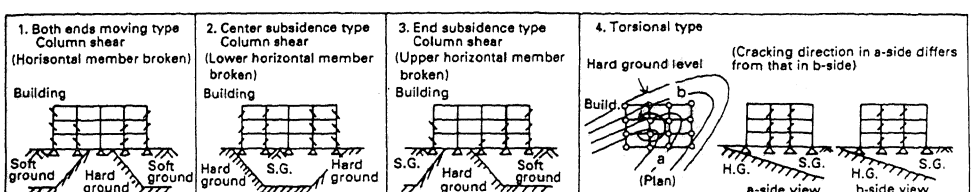


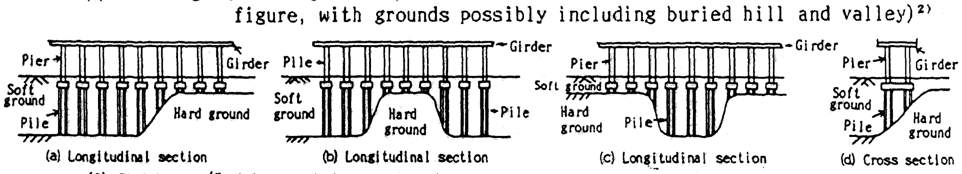
[In cases of (2) (c), (d) and (e), some will deform at right angles to this paper.]

(1) Embankments (possibly including buried hill and valley)



S.G.: Soft ground, H.G.: Hard ground

(2) Buildings (Buildings with pile foundation will also be damaged like this figure, with grounds possibly including buried hill and valley)[2)]



(3) Bridges (Bridges with spread foundation will also be damaged like this figure)

Fig.5 Structures of grounds liable to induce earthquake damage to objects