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SYNOPSIS Hokkaido, Japan was attacked by earthquakes of magnitude 7.8 twice in January and July, 1993. One is the Kushiro-Oki Earthquake and the other the Hokkaido Nansei-Oki Earthquake. River dikes were severely damaged by liquefaction of sand. The former caused liquefaction of subsided dike materials and the latter caused liquefaction of sand of the foundation bed. Relations between dimensional elements of dike and peat bed and stress relaxation within dike were analyzed. Old channels recently filled with sandy materials were distinguished from pointbar zones in ancient river bed covered with silty sediment, based on degree of damage due to liquefaction.

Repairing works were completed by the end of the year precedent the snow season.

1. OUTLINE OF EARTHQUAKES AND DAMAGE ON RIVER FACILITIES

Hokkaido, the northern island of Japan, encountered with earthquakes of magnitude 7.8 twice in January and July in 1993.

The first one is named the Kushiro-Oki Earthquake that occurred at 20:06 on January 15. The epicenter is located at 144° 23'E, 42° 51'N (15 - 20 km offshore Kushiro city), and the depth of the source is 107 km, where is inside Pacific Plate that is creeping down under North American Plate by one third of the thickness below its upper surface.

Observed surface accelerations was 711-919 gal at the Kushiro Local Weather Station. Accelerations of 350-500 gal were obtained within 100 km from the epicenter.

The second earthquake is the Hokkaido Nansei-Oki Earthquake that took place at 22:17 on July 12. The epicenter is 139° 12'E, 42° 47'N, 70 km northward of Okushiri island and the depth of the source is 34 km. This area is considered as a compression field between North American Plate and Eurasian Plate.

These earthquakes brought disasters on kinds of infrastructures such as roads, railways, harbors, river levees and lifelines.

Maximum observed acceleration at ground surface was 216 gal, which was recorded at Suttsu, 88 km from the epicenter and 183-214 gal were also recorded within distance of 200 km.

Epicenters, distribution of damaged river levees and observed maximum surface accelerations are shown in Fig. 1.

Damage of river dikes caused by the Kushiro-Oki Earthquake reached the total length of 26,306 m through 52 sections. Damage of bank protection was 1,260 m at 11 sections. Damage of river dikes caused by the Hokkaido Nansei-Oki Earthquake was 8,915 m through 24 sections and that of bank protection was 3,511 m at 20 sections.

In a few days after earthquake, every damaged section were estimated and classified into six types based on features of destructions and its grade in order to grasp the outline of required measures and its total amount.

In addition, the Hokkaido Nansei-Oki Earthquake brought about a big tsunami that resulted more than 200 victims of habitant of Okushiri island.

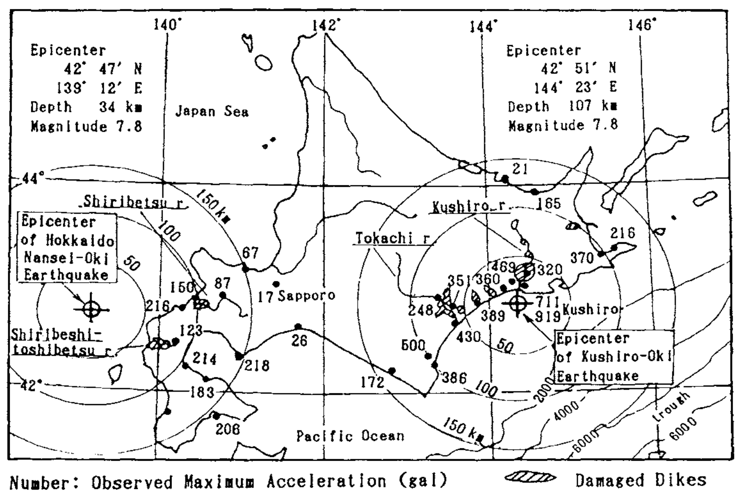

Fig. 1 Epicenters, observed maximum acceleration and damaged river dikes --- Kushiro-Oki Earthquake and Hokkaido Nansei-Oki Earthquake

2. CHARACTERISTICS AND MECHANISMS OF DISASTER ON RIVER LEVEE

2-1 The Kushiro-Oki Earthquake

Along the Kushiro River and the Tokachi River on alluvial lowlands, dikes were given deadly blows in its long extent, while the peripheral surface (marsh and farmland) showed neither conspicuous breakage nor sand eruption. Namely longitudinal cracks spread along slope shoulders or center of crest of levees, often taking vertical gaps and 2 to 3 m of sinking of crest. Mostly waterside slopes were expanded and disrupted. In order to find out the remaining state in the dike after earthquake, boring in every 50-100 m distance on the crest of dike and 5-7 boring at several sites were practiced on cross sections of dikes, where trench cut were carried out so that vestiges of liquefaction might be found and movements of soil blocks might be interpreted. Cone penetration tests were also tried on the trench bottom.

Peaty bed of 3-6 m thickness spreads over alluvial lowlands of the Kushiro River and the Tokachi River forming marsh or farmland. It is characterized by its natural moisture content (Wn) of 200-1000%. Peat bed was underlain by a sand bed and a thick soft marine clay bed.

River levee with its height of 5-7 m had sank so deep into peaty bed as 2 to 3 m prior to the earthquake. Materials of levee are generally sandy soil originated from volcanic ashes and are rather pervious.

Dike material below the ground surface was submerged under ground water and was potentially liquefied by earthquake. Surface of dike and marsh plane beside levee was frozen to the depth of 50-70 cm and was effective to resist against sand eruption through peat bed from sand layer below through peat bed. Fig. 2 shows a sketch of failure of the Kushiro River dike.

2-2 The Hokkaido Nansei-Oki Earthquake

On alluvial planes along the Shiribeshi-toshibetsu River and the Shiribetsu River, dikes were damaged with many longitudinal fissures, sinking of crest, sand eruptions along toe of dikes and notable depression of crest in some sections. Split of the surface and sand eruptions were recognized so much on paddy field and other farmland as well.

The test holes were drilled along toe line of river dike in order to grasp the distribution of sand bed that was supposed to be liquefied. Cross sectional profiles of river dikes were also analyzed basing on 5-7 boring. There profiles were verified in trench cut walls which revealed liquified sand flow upward along cracks and mass movements after liquefaction. Bottom of intruded dike material was explored using Dutch cone and Georadar.

Foundation of dikes of these two rivers generally consists of sandy soil. There is no peat bed and no soft clay bed directly under dikes.

Heavily damaged dikes were seemed to be coincident to "short cut" sections which were executed during 1930s.

Detailed investigation showed that most heavily damaged sections were underlain by silt bed 2-2.5 m thick. The silty bed seems to be "covering layer on pointbar deposit" inside of meandering old river bed. "Old river channels" were filled

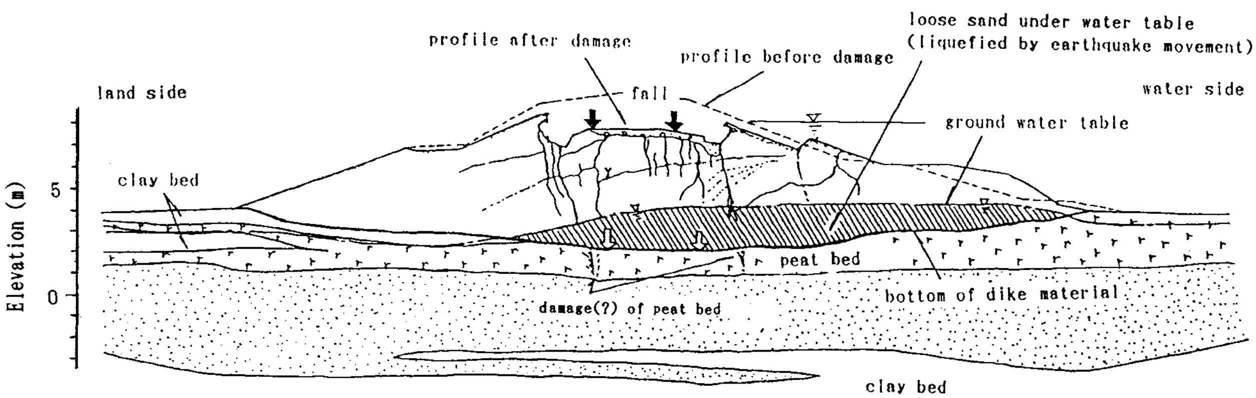

Fig. 2 Analyzed sketch of damaged dike at the Kushiro River left bank 9k850

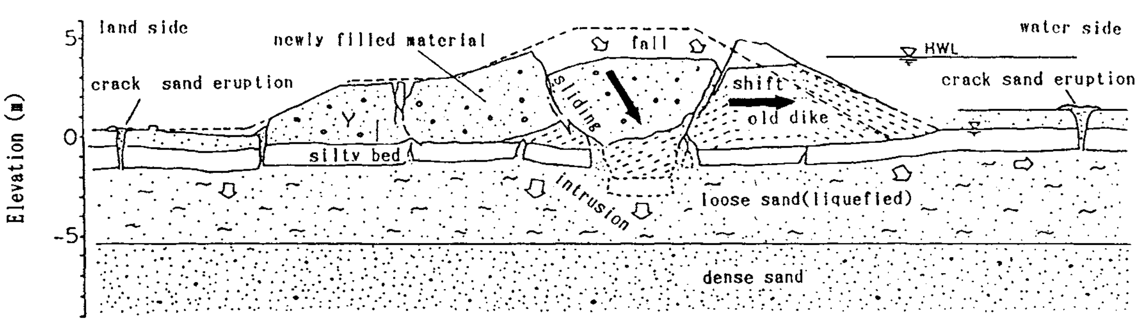

Fig 3. Analyzed sketch of damaged dike at the Kabutono Bank of the Shiribeshi-toshibetsu river

here mainly with sandy materials and have no silty bed and suffered from next severe dames.

Section with no damages or with light damages were found outside of meandering belt of the river.

The silty covering layer is considered resistive to prompt dispersion of excess pore water pressure generated during earthquake movement resulting falls of dike crest.

On the lowest stream of the Shiribeshi-toshibetsu River soil mass under crest fell by 3 m into liquefied sand bed and soil mass under slope was shifted by 3 m horizontally to waterside as shown in Fig. 3.

3. ANALYTIC STUDIES OF DAMAGING MECHANISM

3-1 The Kushiro-Oki Earthquake

Failures of dikes of the Kushiro River and the Tokachi River are symbolized by liquefaction of dike materials sank into peat bed. Consequently the aspect of breakage is often represented by a remarkable fall of the crest of dike.

In order to find out means of estimation of such occurrence of failure verifications of liquefaction just below the crest and analyses of stress relaxation in dike material were carried out.

i) Liquefaction Resistance Factor FL

Kushiro River left bank sank 2.1 m into peat bed and water level in dike rose 1-1.5 m above ground water level. Averaged SPT N-value of dike material under water table was approximately 5 liquefaction resistance factor FL under crest of the Kushiro River right bank at 11k650m was estimated 0.5-0.3 against 180-320 gal of earthquake movement. Observed acceleration exceeded 350 gal and was enough strong to cause liquefaction below the crest of dike.

ii) Study of stress relaxation and liquefaction occurrence in dike.

The lower half of dike must have been in tension field as subsidence proceeds and mean principal stress might be negative to be easy to liquefy in spite of certain overburden.

Model simulation of stress relaxation was practiced to find out conditions which lead liquefaction or avoid it. First, elastic modulus of peat bed coincident to observed subsidence was identified and secondly parametric analyses of stress relaxation in 27 models composed among each 3 values of thickness of peat D (5, 10, 15 m), thickness of dike H (2.5, 5, 10 m) and gradient of slope 1:n (1:2, 1:3, 1:6) were accomplished.

Analytical software was Di-dimensional elastoplastic analysis programme by F.E.M. using EWS. Methodological comparison supposing some failure strains (0%, 0.5%, 1.0% and ∞) in tension quadrant of dike material concluded to adopt linear elastic property both in compressive and tension fields for the sake of simplicity as shown in Fig. 4..

Result of parametric study was digested as follows:

When the ratio of horizontal length of slope (H·n) to thickness of peat bed (D) is less than 7, stress relaxation to lead liquefaction of dike material does not come out also assisted by actual cases.

Fig. 6 gives a comprehensive result of analysis.

3-2 The Hokkaido Nansei-Oki Earthquake

i) Liquefaction Resistance Factor FL

Disasters of the Shiribeshi-toshibetsu River dike and the

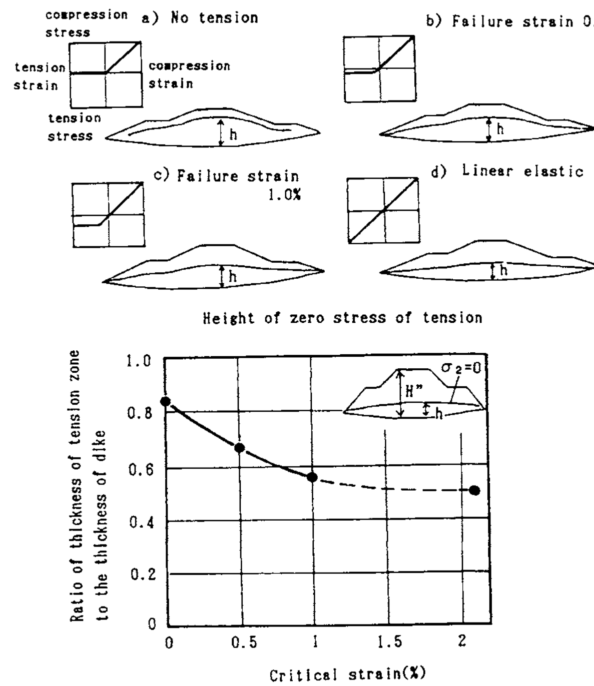

Fig. 4 Critical strain and ratios of thickness of tension zone to the thickness of dike.
--- Minimum principal stress ---

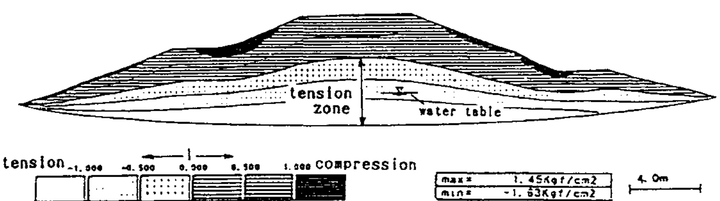

Fig. 5 Stress relaxation Analysis
Difference between mean principal stress inside dikes on rigid base and soft base.
A case of modelled Kushiro river

Shiribetsu River dike were mostly due to liquefaction of sand bed to the depth of 5-6 m. Kabutono site (1 km from mouth of the Shiribeshitoshibetsu River) gave liquefaction resistance factor FL of 0.713-0.534 in sand bed just below the crest against 150-200 gal. Minimum acceleration to cause liquefactions was 126 gal. These estimations are agreeable to observed cases of actual damages.

4. REPAIR WORK

Repair works were divided into two stages, one was that of urgent repair work and the other permanent repair work. Urgent repair works were filling up to the height of the original state, covering dike with PVC sheet and putting

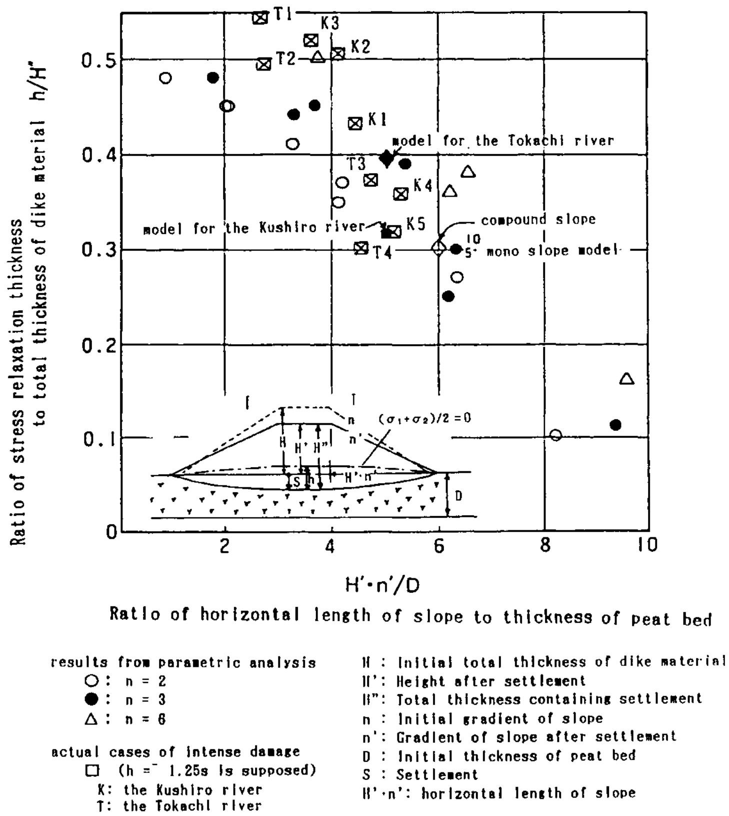

Fig. 6 Result of parametric analysis and actual data of damaged dike.

weight with sand bags.

Main measures of permanent repair works were cut and reembankment. Partial excavation and filling were adopted to cracks which remain above proposed high water level. Most severely damaged sections took additional measure of foundation improvement as sand compaction pile method so that prompt reembankment may be attained without any instability.

The Kushiro River and the Tokachi River were close to thawing flood at hand and the Shiribeshi-toshibetsu River and the Shribetsu River had been already involved in season of floods brought by typhoon. Double steel sheet pile walls were driven in order to hold high water while river dikes were excavated.

Cut and reembankment required careful observing of lime or grout material injected just after the earthquake and cutting bottoms were lowered 1 m below the lower end of observed crack. Radio Isotope Tester was used to control degree of compaction throughout reembankment works. Improvements of foundation were practiced as shown in TABLE I.

Repairing work was completed before snow season.

TABLE I. Measures and numbers of improvement of foundation on each river

River	Measures	Number	
		Site	Length (m)
Kushiro R.	Sand compaction pile	4	1,601
Tokachi R.	Sand compaction pile	1	600
	Pile-net method	1	100
Shiribeshi-toshibetsu R.	Sand compaction Pile	1	130
	Dynamic consolidation	1	70
	Geotextile method	2	320
	Total	10	2,821

(80% in total repaired distance)

5. CONCLUSIONS

Experience and study of successive and contrasive earthquakes in Hokkaido has given such lessons as below.

(1) Two earthquakes introduced here have exhibited different patterns of liquefaction. Considerable subsidence of a river levee brings saturation of dike materials and stress relaxation inside that is a state potentially incurring liquefaction. Ratio of the slope length of dike to the thickness of peat bed can indicate ratio of the relaxation thickness to the total thickness of dike material. So rather gentle slope saves the potential of liquefaction.

(2) Among alluvial micormorphological division, ancient river bed should be at times reassessed according to the material of top soil or artificial filling materials. Surface impervious layer can confine pore pressure and intensify damages.

6. ACKNOWLEDGEMENTS

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