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A STUDY OF THE EVALUATION METHOD FOR EMBANKMENT COLLAPSE RISK

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Abstract

Nowadays, existing earth structures which consist of the important infrastructural network must be needed to endure large earthquake, as well as reinforced concrete structures, metal structures.

Therefore, new earth structures have been aseismic designed, but many earth structures which presents the service of Japan City Railway Network are not aseismic designed because most of them were constructed in old age.

In order to improve the problems, we must consider the appropriate retrofitting strategy, so that we need the method for evaluation collapse risk of earth structures by earthquake.

We investigated and analyzed the property of damaged and no-damaged railway earth structures which had experienced severe seismic excitation. Those were investigated for categorizing with height, slope gradient, geomorphologic classification, and so on. And the influence of each property was analyzed by the assumption point and verification with the database.

According to the results of investigated data, the difference between damaged and no-damaged embankment has a strong correlation to geomorphologic classification, environment around the site, height of embankment, damaged experience, and so on.

Furthermore, we calculated the deformation of damaged and no-damaged railway embankments in 10 areas where severe damage had occurred. We used the Newmark method (modified circular slip surface analysis) for calculating the deformation.

Calculating results revealed that the railway embankments of which yielding intensity is less than 0.3 were severely damaged.

In contrast, those of which the yielding intensity is over than 0.3 was severely in case the groundwater level was high, and the fine fraction content of lower embankment materials or that of upper bearing strata were less than 35%, and bearing strata contained thick organic soil layer.

Being based on the investigated data and the calculation results, this paper suggests the method of evaluation collapse risk for earth structures by real phenomena caused by the 2011 off the Pacific coast of Tohoku Earthquake.

Keywords: embankment, collapse risk, database investigation, circular slip surface analysis

1. Introduction

The 2011 off the Pacific coast of Tohoku Earthquake has severely damaged various structures in wide Eastern Japan area. The earthquake damaged 68 railway embankments managed by East Japan Railway Company (JR East) [1]. A railway transportation is a network system which consists of various type structures, RC viaducts, RC/Metal piers, RC/PC/Metal girders, embankments, cuts, and so on. Therefore, if one of them which consists of the transportation network system was not functional by damage, the system would be not useful. It is suggested that embankments must be aseismic designed because of social demands for the safety and recovery performance of the transportation system preparing for the severe earthquake which would probably break out.

It is important to evaluate the existing structures which has aseismic performance, and to judge which existing structure should be retrofitted. And it is very difficult to establish strategy for prevention and mitigation of earthquake disaster disease, if the aseismic performance of existing structures could be unknown. It is more difficult to evaluate the aseismic performance of earth structures comparing with the other type structures, RC/ Metal Structures, because of the soil characteristic variability of materials.

It is well known by the studies based on statistical methods that embankment damage by earthquake depends on the strength of materials, the performance of bearing strata, geomorphologic environment, seismic intensity, and so on. Furthermore, many studies have shown that each collapsing phenomenon, or damage would be expressed by the circular slip surface analysis based on the investigation results of soil characteristics. And most of studies have not targeted no-damaged examples, but damaged examples. Furthermore, we recognize the problems that the results solved by statistical methods would have the inaccuracy, and that analytical methods would need a high cost, and a long period in order to survey and investigate the proportion and the soil characteristics of embankment materials, and so on.

In this study, we investigate properties of damaged and undamaged embankments by the 2011 off the Pacific coast of Tohoku Earthquake, and we suggest the evaluate method of the aseismic performance of existing railway embankments.

2. Embankment Data suffered from Severe Seismic Excitation

2.1 Investigated Database of Embankments shaken with Severe Seismic Excitation

Fig.1 shows the plots where embankments that JR-East managed were damaged in the 2011 off the Pacific coast of Tohoku Earthquake. The plots include not only severe damaged embankments, but also light damaged ones. We decided to investigate the properties of embankments in the area where many embankments especially were damaged based on Fig.1.

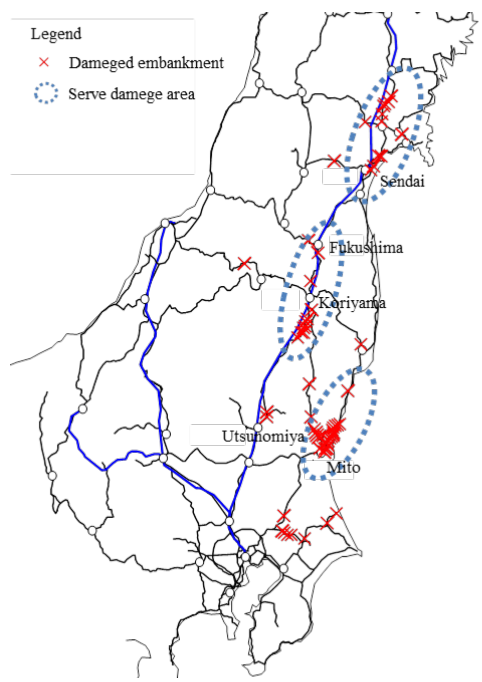

Fig.1 — Embankment Damage Map by the 2011 off the Pacific coast of Tohoku Earthquake(JR-East)

Table 1 shows the length of investigated embankments in severe damaged areas. There are 3 areas where many embankments were damaged, and the total length of embankments in 3 areas is approx. 173km. The property of embankment we investigated is, the height, the slope gradient, the level difference of toe of slope, the geomorphologic classification at the point, the surrounding environment, the measured seismic intensity, the damage experience, whether or not there are facilities for drainage, and they are determined as a rainy weak point. We defined one embankment record as a unit divided at 20m, using the information which had been recorded in civil structure management system managed by JR East (MARS). MARS (Maintenance Assistant System for Railway Structures) is the system for the maintenance and management database of railway structures which JR East is managing and updating [2]. We made database of the records linked to the

Table 1－ Investigation Area

Investigation area	Line name	Investigation				Investigation length (m)	Embankment length (m)
		station 1	station 2	Starting line km	Ending line km		
A	Joban Line	Tomobe	Ueda	99k070m	187k460m	88,390	58,570
B	Tohoku Line	Nishinasuno	Fujita	152k080m	289k290m	137,210	68,990
C	Tohoku Line	Sendai	Ichinoseki	353k640m	440k770m	87,130	45,370
					Total	312,730	172,930

investigated property which are indicated before. One cross section of one unit has two records in case it has slope at both sides(Fig.2).

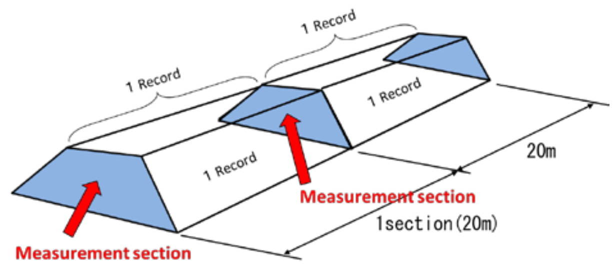

Fig.2 － Embankment unit for a database

Fig.3 shows the definition of the height, the slope gradient, the level difference of a slope of toe. We set the property value using the level information stored in JR-East 3D-GIS alignment at 50cm mesh instead of cross surveying, because the surveying for all records needs a huge cost and a long period. We can calculate the value of each property of embankment by programmed algorithms, for example the height, the slope gradient, the level difference of toe of slope, using meshing elevation and coordinate. We defined the value of the slope gradient of embankment as that of the line connecting the top to the toe of slope, or the toe of footing of retaining wall, by calculating automatically using elevation and coordinate data with programs. We defined a measured seismic intensity as the value calculated value by using data observed by the seismograph which is nearest at the site, managed by NIED (National Research Institute for Earth Science and Disaster Resilience) [3]. We gained the information of geomorphologic classification data from the land condition map edited by Geospatial Information Authority of Japan [4], and Japan Seismic Hazard Station [5].

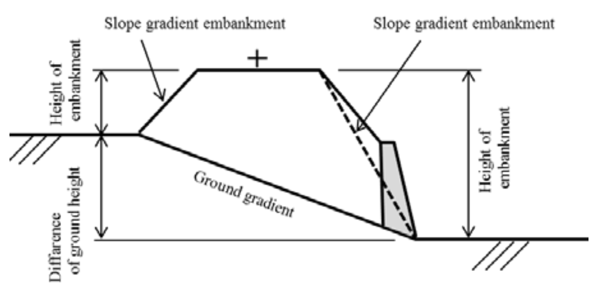

Fig.3－ Properties of Embankment Section

We classified types of the surrounding environment as “mountain”, “river”, “paddy”, “field”, “residential areas”, “road”, and “others”, based on topographic maps and areal maps [4]. We confirmed whether or not the facilities of drainage exist, and the embankment had been damaged in the past, and it is defined as a rainy weak point in MARS. In this study, “the facilities of drainage” is not drainage pipes inserted to core of embankments, but drainages along toe of slope, vertical drains, cross-track drainage works, and so on. We defined that the embankment had been damaged by the record we confirmed in MARS, regardless of the differences of causes (rainfall, earthquake) and damage classification. Rainy weak points of earth structures are defined as the following cases, for example a gradient changing point(a sag), earth structures on the thick soft ground, the boundary between cuts and embankments, earth structures on the landslide site, earth structures on the lower land where water flows around lands. Rainy weak points of earth structures are chosen by JR East civil engineers who majored in railway maintenance engineering based on the topographic maps, pictures, and judgement by the field investigation.

2.2 target embankments for circular slip surface analysis

Fig.4 shows the embankment sites of which safety factor we calculated by circular slip surface analysis. They are assumed to be damaged with the circular slip mode, and repairing works assume to need more than 2 weeks.

Embankment sites contain damaged and no-damaged embankments neighboring with each other. In case the embankment has both side slopes, we tried to investigate soil characteristics, and calculate safety factor by circular slip surface analysis for both side slopes as possible.

Table 2 shows embankment slopes we investigated and calculated. The number in Fig.4 indicates the number of Table 2 site No, and latter letter “D” indicates “damaged”, “N” indicates “no damaged”. Table 3 shows the investigated property of embankments, and soil characteristic property for calculation safety factor by circular slip surface analysis. Because damaged embankments had been repaired at the investigation site, we tried to investigate boundary sites between damaged and no-damaged embankments as possible. We used soil characteristic parameter, c and ϕ with a triaxial compression test（CU and $\overline{\text{CU}}$）in order to evaluate the influence by the underground water level. We wanted to get c, ϕ, under total stress, and c', ϕ' under effective stress, to calculate circular slip surface mode stability considering the influence by underground water level. We measured underground water level using bore hole for the purpose of soil specimen sampling.

Table 2 － Investigation Sites

Site No.	Line name	Station1 - station2	Line km	Slope of embankment	Damaged or undamaged*	Embankment name
1	Tohoku Line	Toyohara - Shirasaka	176k970m	Right	×	1-1D
			177k360m	Right	○	1-2U
2	Tohoku Line	Toyohara - Shirasaka	178k070m	Left	○	2-1U
				Right	×	2-2D
			178k280m	Left	○	2-3U
				Right	○	2-4U
3	Tohoku Line	Izumizaki - Yabuki	200k440m	Left	×	3-1D
				Right	×	3-2D
			200k505m	Left	○	3-3U
				Right	○	3-4U
4	Tohoku Line	Kagamiishi - Sukagawa	210k650m	Right	×	4-1D
			211k300m	Right	○	4-2U
5	Tohoku Line	Umegasawa - Nitta	412k427m	Left	×	5-1D
			412k540m	Left	○	5-2U
6	Tohoku Line	Nitta - Ishikoshi	420k820m	Right	×	6-1D
			420k980m	Right	○	6-2U
7	Joban Line	Sanuki - Ushiku	48k620m	Left	○	7-1U
				Right	○	7-2U
			48k995m	Right	×	7-3D
8	Joban Line	Tokai - Omika	134k900m	Left	○	8-1U
			134k940m	Left	×	8-2D
9	Senzan Line	Sakunami - Yatsumori	30k200m	Left	○	9-1U
			30k295m	Left	×	9-2D

*○：undamaged, ×：damaged

3. The Results of Data Investigation an Analysis

3.1 The relationship between damage occurrence ratio and each property of embankments

We define the index, which we call it the ratio of damage occurrence, in order to analyze investigated data base.

The ratio of damage occurrence is defined as follows,

$$RD = Na/Nd \times 100 \tag{1}$$

where

RD：the ratio of damage occurrence（%）

Nd : the number of records which were damaged in each category

Na : the total number of records which belong to each category in severe damaged 3 areas

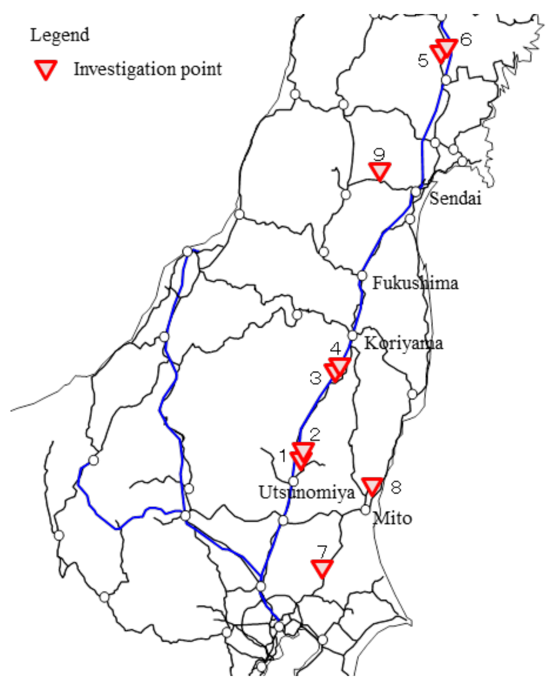

Fig.4 － Investigation Location Map

Table 3－ Upper and lower embankment material properties

Damaged or no-damaged	Embankment name	Wet density ρ_t (g/cm^3)		Cohesion c* (kN/m^2)				Internal friction angle φ* (degree)				Degree of saturation S_r (%)		Fine fraction content F_c (%)	
		Upper	Lower	Upper		Lower		Upper		Lower		Upper	Lower	Upper	Lower
				c	c’	c	c’	φ	φ’	φ	φ’				
Damaged	1-1D	1.417	1.418	12.5	2.8	37.7	8.9	15.7	33.9	14.2	33.0	91.6	92.6	80.6	90.0
	2-2D	1.468	1.473	9.3	11.4	6.6	7.4	17.5	26.7	19.9	29.4	82.6	97.3	81.4	90.6
	3-1D	1.672	–	14.3	9.5	–	–	16.2	30.6	–	–	97.2	–	68.1	–
	3-2D	1.654	–	7.9	2.7	–	–	17.3	34.4	–	–	96.8	–	58.7	–
	4-1D	1.680	–	16.7	12.1	–	–	20.3	31.9	–	–	89.3	–	81.0	–
	5-1D	1.724	1.762	51.1	16.0	31.6	7.3	11.1	26.7	20.0	34.1	57.0	84.0	37.6	26.1
	6-1D	1.620	–	19.9	3.5	–	–	10.7	27.3	–	–	79.7	–	39.5	–
	7-3D	1.644	1.445	10.0	9.8	17.0	13.7	18.3	32.2	14.4	26.4	67.2	94.8	30.3	68.1
	8-2D	1.620	1.768	53.6	16.2	15.8	4.7	11.4	34.9	17.3	32.0	86.9	94.5	53.0	27.3
	9-2D	1.729	–	13.9	13.7	–	–	11.5	19.1	–	–	98.2	–	57.3	–
Un-damaged	1-2U	1.452	1.437	26.9	5.9	19.2	7.1	12.8	30.0	17.1	33.5	95.4	95.7	82.5	89.0
	2-1U	1.377	1.573	58.7	8.7	21.9	6.8	15.8	37.6	20.5	36.0	89.1	87.7	92.0	73.7
	2-3U	1.375	1.598	22.2	11.0	12.0	7.2	16.5	31.2	17.3	30.1	80.8	94.2	83.1	88.6
	2-4U	1.686	1.535	23.2	19.4	–	–	13.5	20.0	–	–	98.7	98.8	54.3	78.0
	3-3U	1.640	–	20.6	13.8	–	–	16.4	29.6	–	–	88.1	–	62.3	–
	3-4U	1.633	–	26.5	12.2	–	–	15.9	29.4	–	–	96.4	–	61.9	–
	4-2U	1.826	–	8.1	8.1	–	–	23.7	32.4	–	–	99.4	–	60.0	–
	5-2U	1.742	1.787	62.0	13.5	45.5	0	7.6	13.5	19.7	37.1	90.0	93.2	27.5	39.0
	6-2U	1.633	1.643	0	0	0	0	19.5	31.7	20.5	32.8	82.3	96.7	43.2	91.3
	7-1U	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	7-2U	1.643	1.462	27.5	3.0	9.1	5.3	13.6	29.8	21.2	33.3	82.1	91.6	32.3	68.3
	8-1U	1.620	1.673	6.2	4.8	45.7	18.9	25.9	35.8	10.8	28.4	79.3	82.2	54.2	37.5
	9-1U	1.797	1.710	14.9	3.2	10.7	0	15.6	26.6	16.5	22.2	93.7	95.9	29.3	52.5

*c, ϕ : Total stress data , c' , ϕ' : Effective stress data, ** ” –” : No data

Table 4 – Embankment Damage classification by earthquake

Classification	Damage Details	Settlement at top of embankment
Large scale	The settlement or collapse of embankment which needs much repair	over 50cm
Middle scale	The settlement of embankment which needs little repair, or slope failure which could be repaired in a few days.	Over 20cm less than 50cm
Small Scale	The light damage which will not be influent with train operation (ex: cracks at top of slope)	Less than 20cm

We calculated the ratio of record numbers which were damaged by all record numbers, every classification which we categorized based on investigated data. We will try to confirm the influence of each property to the embankment collapse and damage risk by earthquake according to the ratio as we calculated. A damage classification is defined as Table 4.

We categorized those as “undamaged” records, which didn’t belong to any category which we determined before. Because damage survey had been done slightly after earthquake, there was not the high accurate record of the amount of vertical settlement, settlement width, etc. Therefore, we heard the engineers who had investigated around damage structures slightly after the earthquake, based on the pictures which they took. Based on the information that they said, we categorized the damage scale of each embankment. Fig.5-11 and Table 5 show the relations between the RD and each property which we investigated.

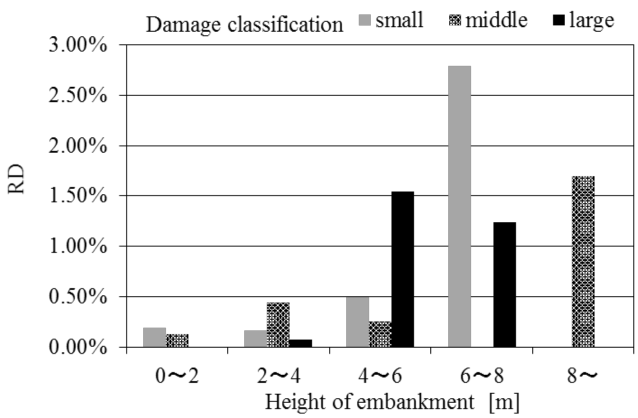

Fig.5 – RD and Height of Embankment

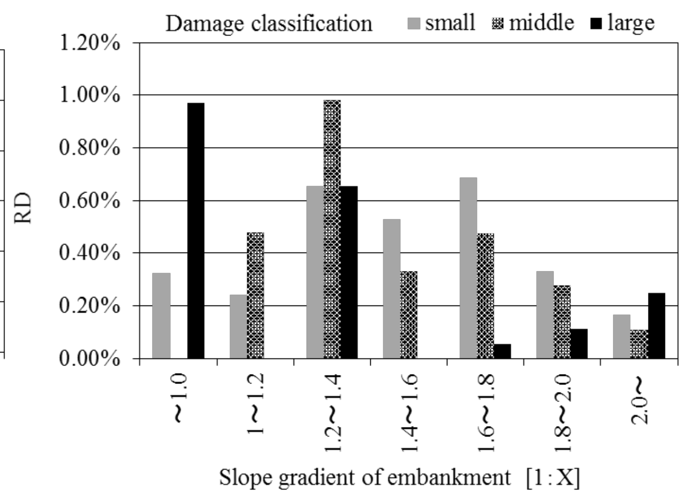

Fig.6 – RD and Slope gradient of Embankment

Table 5 – RD and Geomorphologic classification

Liability of quake	Geomorphologic classification	RD [%] Damage scale large	Damage scale middle	Damage scale small	Corresponding record / total record [%]
Small	Mountains	0	0	5.6	0.9
	Slope	0	0	0	1.0
Middle	Talus cone, Colluvial foot of slope, Debris-flow lobe	0	0	0	0.1
	Hills	0.4	0	0	6.9
	Volcano hills	0.6	1.0	0	5.9
	High terrace	0.4	0.8	0	1.5
	Middle terrace	3.6	0	0	0.4
	Low terrace	0	0	0	0.1
	Diluvial plateau	0	0	0	1.2
	Plateau terrace	0	0	0	0
	Gravel plateau	0.1	0	0	18.4
	Loam plateau	0.1	0.5	0.5	11.9
	Alluvial fan	0	0	0	1.3
	Cut-slope	1.2	10.4	0	0.5
Middle large	Concave slope	0	0	0	0.2
	Natural levee	0	0	0	0.9
	Natural levee, sand bar, sand bank	2.2	0	2.2	0.6
	Valley bottom plain, flood plane	0.3	0.1	0.2	16.7
	Valley lowland	0.1	0.1	0	14.3
	Flat	1.4	0	0	0.9
Large	Coastal plain, delta	0	0	0	0.8
	Delta, coastal lowland	0	0	0	4.4
	Back lowland	4.0	0	3.0	2.5
	Back marsh	0	0	0	2.2
	Old river channel	0	0	0	0.1
	Embankment	0	0.3	0	3.7
	Backfill	0	0	0	0.2
	Polder	0	1.2	0	1.6
Out of valuation range	High-water channel	0	0	0	0.3
	Shore	0	0	0	0.3
	Water space	0	0	0	0.3

(1) the Height of Embankment

Fig.5 shows the relation between the RD and the height of embankments. Focusing on the embankment which of the damage classification is large scale and middle scale, in case the height of embankment is higher than 4.0m, the RD has a tendency to be high, based on the data which Fig.5 shows.

(2) the Slope Gradient of Embankment

Fig.6 shows the relation between the RD and the slope gradient of embankments. The value of the horizontal axis indicates the slope gradient. The smaller the value is; the steeper slope of embankment is. Focusing on the embankment which of the damage classification is large scale and middle scale, we can confirm that the steeper slope of embankment is, the higher the RD is.

(3) the Geomorphologic Classification

Table 5 shows the relation between of the RD and the geomorphologic classification. We set the geomorphologic ground types on the field in Table 5, as the upper field doesn't have a tendency to be shaken severely by earthquake, based on references [6]. We can confirm that the RD has a tendency to be higher on the geomorphologic ground types which are severely shaken by earthquake. But, we can confirm the mountain site is exception. Focusing on the embankment which of the damage classification is middle scale, the RD is high in case the embankment exists on cut slopes, volcanic hills. The fact that the RD is high in case the embankment is on volcanic hills is harmonic with an existing study [7]. These results show that it is difficult to evaluate damage classification by the only geomorphologic ground types.

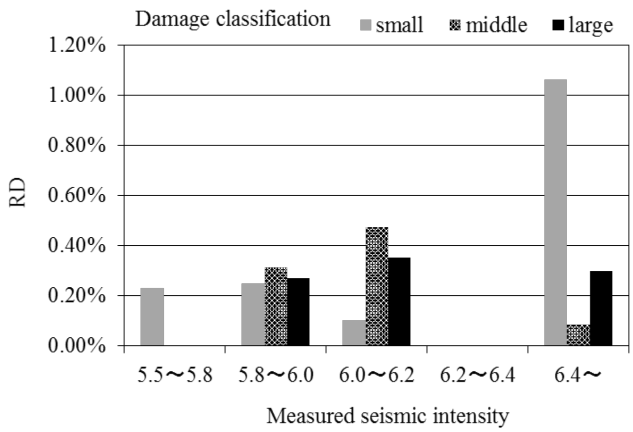

Fig.7 – RD and Measured Seismic Intensity

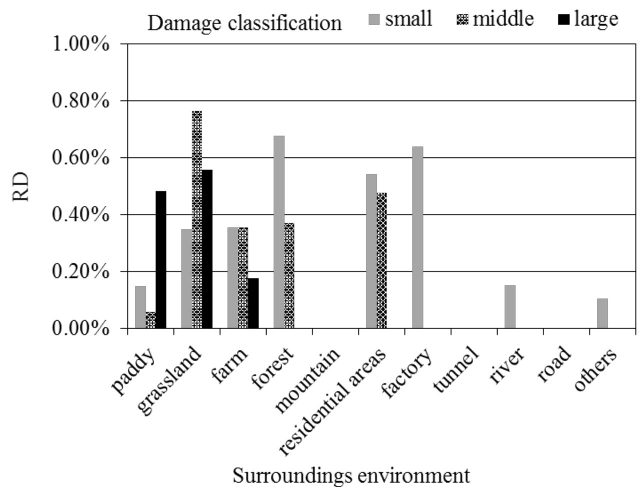

Fig.8 – RD and Surrounding Environment

(4) the Seismic Measured Intensity

Fig.7 shows the relation between the RD and the measured seismic intensity. The all embankment damage occurred in areas where the measured seismic intensity was observed over 5.5. Furthermore, the embankment of which damage classification is middle scale or large scale were damaged in the area where the measured seismic intensity had been observed over 5.8, by the seismograph which is nearest from the site.

We can confirm that the larger the measured seismic intensity is, the higher the RD is overall. This result is harmonic with existing acknowledgements and studies[7], [8], which indicates the relationship structural damage with JMA(Japan Meteorological Agency) seismic intensity classification, and that we could confirm the structural damage and embankment damage in case the measured seismic intensity was over 5.0〜5.5.

(5) the Surrounding Environment, the Facilities of Drainage, Rainy weak point

Fig.8 shows the relation between the RD and the surrounding environment. Fig.8 indicates that the RD is high in paddies, grassland, and farm. The large scale damage embankments have a tendency to be in these surrounding environments by Fig.8. We assume that embankments at the area where water is supplied on the plane ground from surrounding landforms, and plants can grow easily, will be easily damaged by these results. Fig.9 shows the relation between the RD and the existing of drainage facilities. We can confirm that the RD is higher in case there were not drainage facilities overall by Fig.9. Fig.10 shows the relation between the RD and the damage experience. Fig.11 shows the relation between the RD and the rainy weak point. We can confirm that the embankments which had been damaged once in the past have a tendency to be damaged again by earthquake by Fig.10. And we can confirm that most of large scale damaged embankment exists on the sites which we had set as the rainy weak point by Fig.11. According to this result, we can assume that the embankment in the area where water is supplied would be easily damaged by earthquake.

3.2 The Result of Circular Slip Calculation for Damaged and Undamaged Embankments

We used the Newmark method in order to evaluate deformation of embankments. The Newmark method is well known as the method which could evaluate the deformation of embankments using easy model which is a kind of circular slip surface analysis method. We set that each coefficient is 1.0 in calculation because the purpose of these analysis was not to design them, but to evaluate real phenomena. We set the parameter for the calculation as follows, based on the bore hole investigated results, and triaxle compressive test results.

・Above the underground water level: cohesion *c*, inertial friction angle(ϕ), under the total stress.

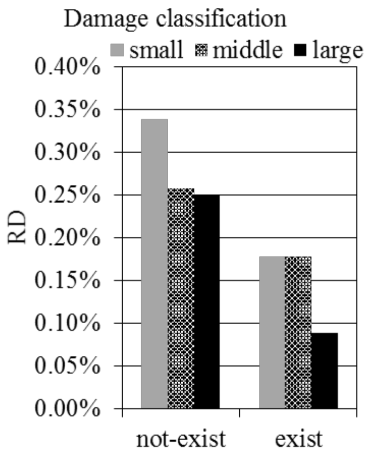

Fig.9 – RD and drainage facilities

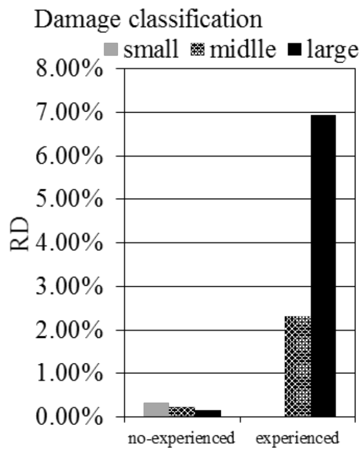

Fig.10－RD and Damage Experienc

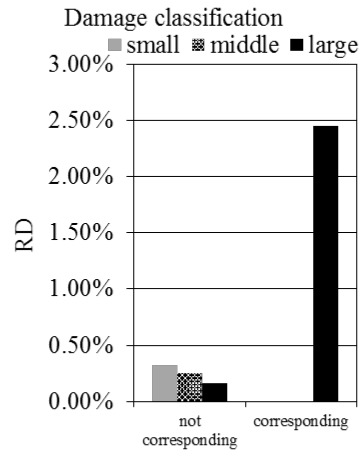

Fig.11－RD and Rainy weak point

・Under the underground water level: cohesion *c'*, inertial friction angle(ϕ '), under the effective stress.

Seismic wave for calculation is compensated on the basis of the data which was observed by the nearest seismograph from the target area, which NIED managed. We compensated observed ground surface seismic wave to an engineering base surface seismic wave by equivalent linearizing method. Then, we compensated seismic wave on site by the same method based on an engineering base surface seismic wave which we calculated and boring data on the site. Next, we compensated seismic wave whose excitation direction is crossing alignment by angle because seismic wave is observed on two axes, N-S direction, E-W direction.

Fig.12 shows that the relation of observed deformation of embankment and calculation deformation results. We cannot confirm clear correlation of observed data and calculated data. We are assuming the causes of this result as follows.

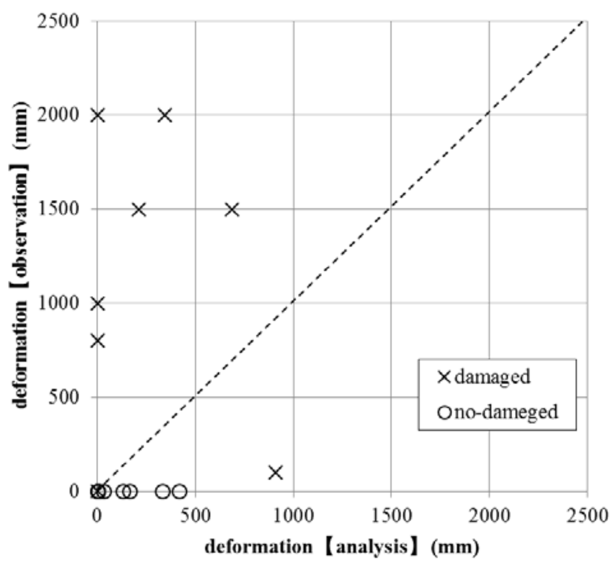

Fig.12 – A Comparison of Deformation Between Observation and Analysis

・Circular slip surface shape which is calculated in case the safety factor is the smallest, is different from that of real phenomena.

・The real phenomena have several deformation modes, not only circular slip mode, but also settlement mode of embankment.

・There is a soil characteristic variability in material of embankment, and bearing strata.

・There is the difference between a compensated ground surface seismic wave and a real seismic wave on site.

Table 6 shows the yielding intensity of a circular slip mode of each embankment. A circular slip surface shape is calculated by programmed algorithms which simply seeks the weakest shape, and is not set by the judge of engineers. The reason why we do so is that the purpose of this study is not a reproducibility analysis, but the evaluating method of embankment collapse risks. Table 6 shows that the embankments which had not been damaged in the past, were not damaged by the 2011 off the Pacific coast of Tohoku Earthquake.

Table 6－Circular Slip Surface Analysis Results and Other Properties

Damaged or no-damaged	Embankment name	Observation maximum earthquake acceleration (gal)	Compensated maximum earthquake acceleration (gal)	Yielding intensity	Deformation【Analysis】(mm)	Deformation【Observation】(mm)	Height of embankment (m)	Soft bearing stratum	Damaged experience
Damaged	1-1D	1191	927	0.145	910	100（Crack）	19.8	○	×
	2-2D	1086	443	0.03	3132	500（Crack）	11.2	×	○
	3-1D	412	307	0.288	1	2000	5.3	○	○
	3-2D	412	307	0.101	343	2000	6.1	○	○
	4-1D	548	327	0.585	0	800	2.8	○	×
	5-1D	2475	3028	0.686	211	1500	5.4	○	○
	6-1D	1690	2419	0.34	685	1500	5.0	○	○
	7-3D	524	205	0.255	0	1000	6.1	○	○
	8-2D	613	51	0.595	0	Minor	5.0	○	×
	9-2D	510	938	0.102	1797	Decay	6.5	×	×
Un-damaged	1-2U	1247	421	0.111	330	—	20.4	×	×
	2-1U	1086	901	0.515	32		1.8	×	×
	2-3U	1086	962	0.026	4362		13.0	×	×
	2-4U	1086	931	0.137	417		16.4	×	×
	3-3U	412	65	0.381	0		5.6	○	×
	3-4U	412	65	0.338	0		6.1	○	×
	4-2U	548	525	0.244	164		5.4	×	×
	5-2U	2475	2799	0.852	131		7.0	×	×
	6-2U	2402	1029	0.01	25631		5.8	○	×
	7-1U	524	142	0.451	0		2.9	○	×
	7-2U	524	142	0.442	0		3.8	○	×
	8-1U	613	141	0.452	0		4.2	○	×
	9-1U	510	1151	0.01	25296		9.0	×	×

*○：corresponding, ×：not corresponding

Especially, we can confirm that damaged embankments were on the soft ground, comparing with undamaged embankments by Table 6. These results indicate that we would not be able to evaluate the embankment collapse risks by the only investigation of soil characteristics and calculation using a circular slip surface analysis. And it is necessary for us to consider the information of the bearing strata performance and the damage experiences in order to evaluate the embankment collapse risks.

4. Suggestion of the Damage Risk Map of Embankments

4.1 The Assumption Point of Each Property of Embankment

We tried to know the quantitative influence of each property of embankments to damage scale by earthquake using the flow as indicated in Fig.13. Although we have a method to be widely known as the mathematical quantification theory, we used the aforementioned method as the following reasons.

・The result parameter is qualitative, and the parameters of causes contain not only quantitative data(the height, and the slope gradient), but also qualitative data （the geomorphologic classification, the surrounding environment,…etc.）.

Using damaged embankment records, we tried to set the assumption point of each property and threshold point, so that the probability of evaluating damage classification “large scale” is over 80%, and that of doing damage classification “middle scale” is over 60% by the summation of each assumption point. Next step, we evaluated undamaged embankment records by this assumption point. And we will continue to set the assumption point of each property and the threshold point until the certainty of evaluating damage classification “large scale” is over 80%, and that of doing damage classification “middle scale” is over 60%. We indicate the setting the assumption point of each property and threshold point in detail, as follows.

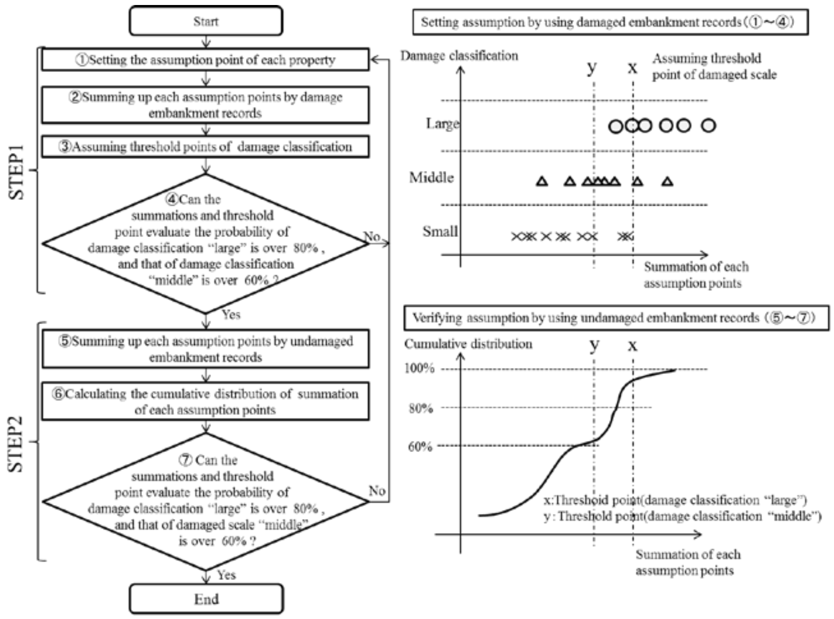

Fig.13—A Flow for the Setting Assumption Point of Each Property of Embankment

【STEP1 : Flow Chart ①～④】

Using the damaged embankment records, we will set the assumption point of each property and assumption threshold point which could evaluate the probability of a damage classification "large scale" is over 80%, and the probability of damage classification "middle scale" is over 60% (Fig.14).

【STEP2 : Flow Chart ⑤～⑦】

Using the assumption point of each property at STEP1, we will calculate each summation of all undamaged embankment records. And we will confirm the cumulative distribution of each summation value of undamaged embankment records (Fig.15). Next, we will confirm that the cumulative distribution value of undamaged embankment records is over 80% in case the value is over the assumption threshold(large) point, and that is over 60% in case that is over the threshold(middle) point.

If aforementioned condition is satisfied, we will finish the set of the assumption point of each property and the threshold point. If it isn't, we will reset them back to STEP1. This method is similar to the statistical hypothesis testing by certificating the assumption points we set by using damaged embankment records, with undamaged embankment records. We indicate one example of the assumption point of each property which satisfy the aforementioned conditions in Table 7. Although, we will need to check the assumption point of each property and the assumption threshold point by using damaged and undamaged embankment records by another large scale earthquake because these are analyzed in the limited areas.

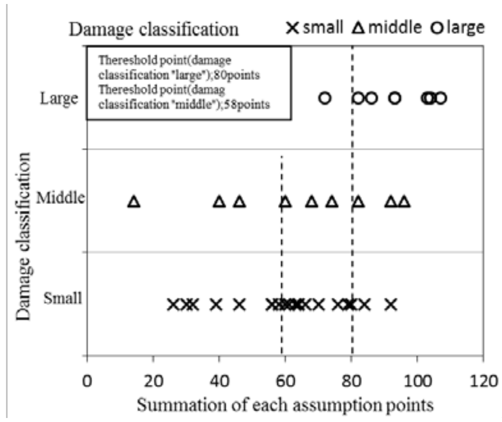

Fig.14—Damage Classification and the Summation of the Assumption Points with Using Damaged Records

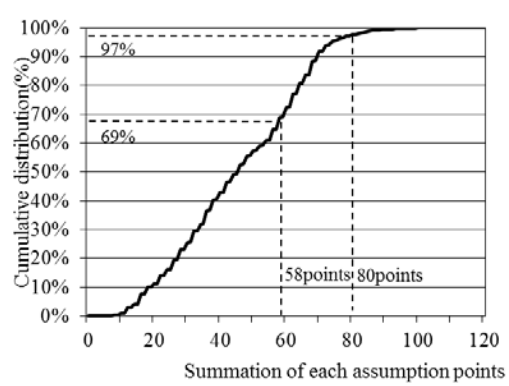

Fig.15—Cumulative Distribution of no damaged Embankments According to the Summation of Assumption Points

4.2 The evaluation method of yielding intensity and the assumption point

Fig.16 shows the plot which indicates the summation of assumption point and yielding intensity about damaged, undamaged embankments. We can confirm that the damaged embankments exist in the area where the summation of assumption point is high, and yielding intensity point is less than 0.3 in Fig.16. Furthermore, we can confirm that damaged embankment exists in case its yielding intensity is less than 0.2, regardless of the low summation value of the assumption points (9-2D).

Table 7 －A Sample of the Assumption Point

Survey items	Classification	Point	Range (Influence)
Height (H) [m]	H＜2	0	20 (0.1)
	2≦H＜4	2	
	4≦H＜6	10	
	6≦H＜8	15	
	8≦H	20	
Slope gradient (1:x)	2.0≦x	0	10 (0.1)
	1.6≦x<2.0	2	
	1.4≦x<1.6	4	
	1.2≦x<1.4	6	
	1.0≦x<1.2	8	
	x<1.0	10	
Geomorphologic classification	Others	0	30 (0.2)
	Talus cone, colluvial foot of slope, debris-flow lobe, hills, high terrace, middle terrace, low terrace, diluvial plateau, plateau terrace, gravel plateau, alluvial fan	10	
	Concave slope, valley lowland, flood plain, valley lowland, flat	20	
	Mountains, Volcano hills, loam plateau, cut-slope, natural levee, natural levee･sand bar, sand bank, coastal plain, delta, delta･coastal lowland, back lowland, back marsh, old river channel, embankment, backfill, polder	30	
Surroundings	Others	0	30 (0.2)
	Farm, grassland Paddy field	30	
Drainage	Exist	0	2 (0.1)
	Not exit	2	
Measured seismic intensity (I)	I <5.8	0	10 (0.1)
	5.8≦I<6.0	4	
	6.0≦I<6.2	6	
	6.2≦I<6.4	8	
	6.4≦ I	10	
Disaster experience	Not exist	0	20 (0.1)
	Exist	20	
Rainy weak point	Corresponding	0	15 (0.1)
	Not corresponding	15	
Total point (max)		137	

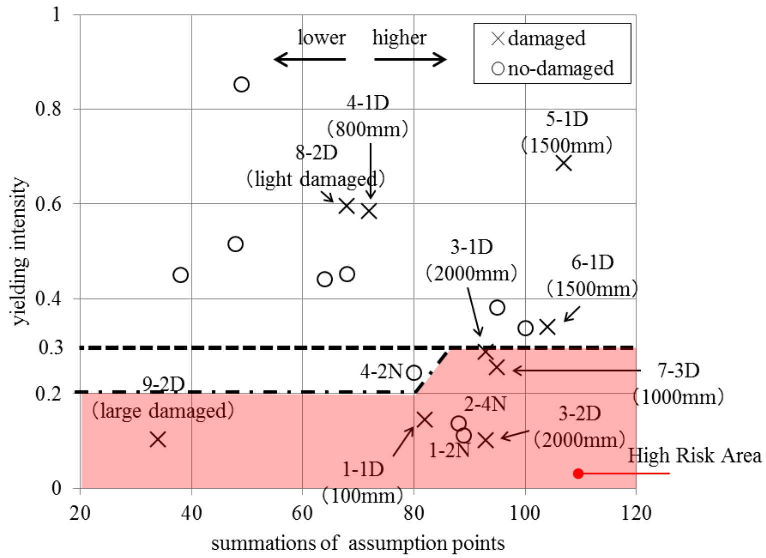

Fig.16－The Relation Between Yielding Seismic Intensity and the Summations of Assumption Points

5-1D, 6-1D, 4-1D, 8-2D were damaged, although yielding intensity of them is over 0.3. The reason why 5-1D, 6-1D were damaged is assumed to be shaken by very severe excitation, where the nearest seismograph observed 2475gal, 1690gal as the max acceleration. About 5-1D, 6-1D, 8-2D, we can confirm that underground water level is high, and the underground water level exists in the lower embankment. And the fine fraction content of the upper bearing strata and the embankment material is less than 35%. And we can confirm that the bearing stratum of 4-1D has a 0.8m organic soil layer, and underground water level is high.

1-2U, 2-4U, 4-2U were not damaged although the summation of assumption point is high and yielding intensity is over 0.3. Common feature of 1-2U, 2-4U is that they exist on the bearing strata of diluvial gravel, rock. The reason why 4-2U was not damaged regardless of the damage of 4-1D, is that the bearing strata don't have organic soil layer, and are not slope layers but level layers.

9-2D was damaged although its summation of assumption point is small. The reason why it was damaged assumed to be that it was covered with snow, and meltwater was supplied to embankment because it exists on the valley.

By these information and results, we can assume comprehensively that the collapse risk of embankment is high in case its summation of assumption point is over 80 point and its yielding intensity is less than 0.3, yielding intensity is less than 0.2 regardless of the low summation of assumption point.

The study of a relationship between the evaluated risk and seismic yielding the intensity will be required for us in order to choose appropriate seismic retrofitting methods based on the evaluated risk. The study of the thesis contributes to constructing strategies of effective and economical seismic retrofitting projects. For example, in case the estimated damage risk value is lower than the threshold value, we should choose an easy method, typified by setting gabions at slope toe. In case it is higher than that, we should do a tough method, typified by constructing stick members into embankments.

5. Acknowledgements

This study presents a suggestion of evaluating collapse risk methods for railway embankments in Eastern Japan, according to the assumption point and yielding intensity of circular slip mode with studying real phenomena by the 2011 off the Pacific coast of Tohoku Earthquake. Acknowledgement is given as follows.

We can confirm that the collapse and damage risk of embankments by earthquake is high, if the yielding intensity is less than 0.3, and the summation value of the assumption points in each embankment property is over 80. And the risk is high in case the yielding intensity is less than 0.2 regardless of the low summation value of the assumption points.

The property of the embankment which strongly influences the collapse damage risk, for example, the height, the slope gradient, the existence of drainage facilities, the measured seismic intensity, the corresponding of the rainy weak point. Although the yielding intensity of embankments is high, some embankments have collapse or damage risks in case bearing strata and lower embankment material contained organic soils, sands whose fine fraction content is less than 35%, and underground water level is high, we are assuming.

We will try to improve accuracy of evaluating embankment damage risk, by fitting analytical circular slip surface with real phenomena, and resetting the assumption point by using the database of other huge earthquakes. Furthermore, in order to evaluate embankment damage risk accurately, the study based many numerical analyses for neighboring embankments which were damaged and not damaged will be desired in the future. And we want researchers all over the world to check the accuracy of this method in case various type earthquakes.

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