INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

SIMSG ISSMGE

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

The paper was published in the proceedings of the 7th International Conference on Earthquake Geotechnical Engineering and was edited by Francesco Silvestri, Nicola Moraci and Susanna Antonielli. The conference was held in Rome, Italy, 17 – 20 June 2019.

Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions – Silvestri & Moraci (Eds)
© 2019 Associazione Geotecnica Italiana, Rome, Italy, ISBN 978-0-367-14328-2

A statistical method to predict the shape of an embankment collapse during the earthquake

R. Sawada
JR Soken Engineering Co., Ltd, Japan

ABSTRACT: Regarding embankment collapses due to earthquakes, there are various shapes. Therefore, it is essential to predict the shape of the embankment collapse to determine effective countermeasures. In addition, a result of prediction of the shape of an embankment collapse is applicable to a risk evaluation model, which determines priorities and countermeasure methods of disaster prevention for existing railway embankments. Accordingly, we analyzed using Hayashi's quantification methods to previous data of the railway embankment collapses due to earthquakes, and developed a method capable of predicting the shape of the embankment collapse from various embankment conditions.

1 INTRODUCTION

Embankment and other soil structures are characterized by their ability to recover quickly even to a certain degree of disaster as they are more easily repaired than structures such as bridges when damaged against external forces such as earthquakes. However, when it is necessary to secure the function as a "line" like a railway, it is desirable that all the structures including the embankment have the same performance.

The main factors of the collapse of the embankment in the previous earthquake are the collapse of the embankment due to the rise in excess pore water pressure, the basal fracture of the ground, the flow of the embankment due to the lateral flow, etc. However, the soil structure like embankment varies depending on the shape and scale of the disaster, such as the case of damaging the operation of the train or the case of minor damage.

Methods to estimate the collapse size of embankments and cut targeting rainfall and to determine the priority of disaster prevention measures have been studied, Sugiyama et al (2008), and some of them have been introduced into maintenance standards, RTRI (2007). However, there are few studies on prediction of collapse degree due to earthquakes, Nakamura et al (2013).

Therefore, we analyzed the case of collapse caused by past earthquakes targeting embankment statistically, predicted various conditions of collapse, collapse shape and degree, and investigated a method to contribute to the plan of disaster prevention measures based on the influence on the operation of the train.

2 EXAMINATION OF PREDICTION METHOD BY HAYASHI'S QUANTIFICATION METHODS

As a method for predicting earthquake damage of embankment, a method of grasping safety factor and deformation quantity by numerical analysis such as stable calculation of embankment can be considered, but as described above, the extended distance of embankment is long, and for all embankments. It is not realistic to make stable calculations and predict.

Therefore, as a realistic evaluation method, it first decides the presence or absence of damage occurrence and grasps the extent of damage by numerical analysis such as stable calculation for the part where damage is expected to occur. In this case, screening is generally adopted for judging the occurrence of damage, and a representative embankment expected to suffer damage will be selected based on the result, but the construction condition of the embankment, there is no discrimination method considered in consideration.

Therefore, in this research, we considered the following as a basic idea and examined a method to determine whether damage occurred considering practicality in consideration of efficient disaster prevention planning for already used embankment.

Therefore, in the study, the collapse shape of the embankment considered to be able to perceive the presence or absence of damage as not the amount of deformation of the embankment, but rather the degree of influence on the train operation and the difficulty of the restoration work relatively easily We quantitatively analyzed factors influencing the collapse shape according to the quantification theory and examined the discrimination method for carrying out the screening.

Here, the collapse shape is based on the classification of the destruction form obtained from the result of the earthquake damage analysis of the embankment, Nozawa (1986), and as shown in Figure 1, as the collapse of the embankment, the slope surface runoff (collapse shape I), slide failure (collapse shape II) of the embankment and destruction of the ground (collapse shape III) were made. In the collapse shape I, the shear strength of the soil on the slope surface is insufficient, causing a sliding failure parallel to the slope surface due to the seismic motion. In the collapse shape II, the shear strength of the soil inside the embankment is insufficient, and due to the seismic motion, sliding failure of a shape close to a circular arc occurs. Collapse shape III is the destruction of the bearing stratum including the liquefaction caused by seismic motions due to insufficient strength of the bearing stratum of the embankment. Among them, the collapse forms I and II are made to coincide with the collapse shape in rainfall in existing research, Sugiyama (1997).

To investigate, 59 embankments were used, with comparatively embankment conditions etc. being clarified, from the damage report of the earthquake which caused the damage of railway embankment caused by the earthquake so far was remarkable. Among them, the collapse shape I is 6, the collapse shape II is 34, and the collapse shape III is 19.

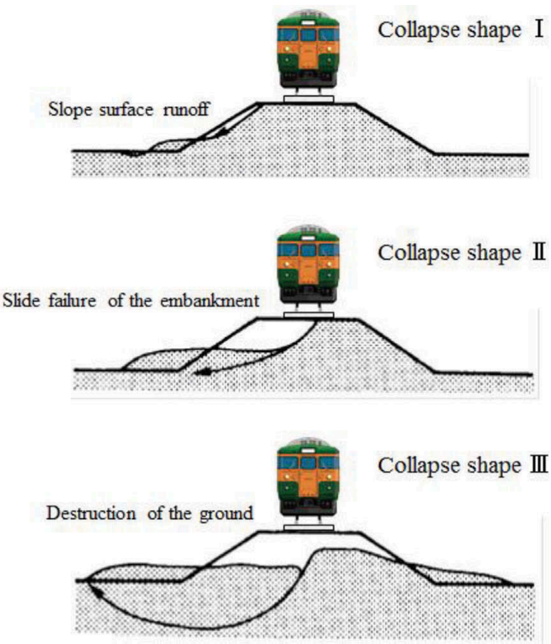

Figure 1. Collapse shape of embankment

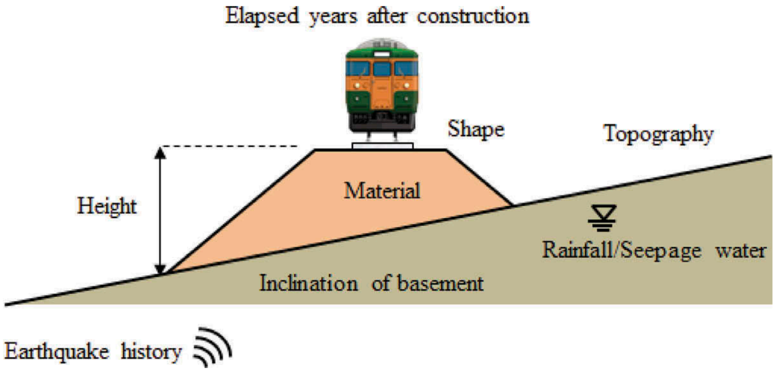

Figure 2. Embankment condition used for study

Table 1. Conditions for predicting collapse shape (various conditions of embankment)

Embankment condition	Category
Earthquake history	Yes, No
Rainfall/Seepage water	Yes, No
Topography	Plateau/Scarp/Terrace, Valley plain, Alluvial fan, Lowland
Embankment height, RTRI (2007)	Less than 9 m, 9 m ~ 15 m, 15 m or more
Embankment shape	Embankment, Widening of embankment, Half-bank and half-cut
Embankment material, RTRI (2012)	Soil type I/II, Soli type III, Soil type IV※
Inclination of basement	Flat, Inclination, Basin
Elapsed years after construction	Less than 10 years, 10 years ~ less than 50 years, Over 50 years

※ Soil type I is well-graded sand and gravel. Soil type II is common sand and gravel. Soil type III is poorly-graded sand. Soil type IV is clay.

In addition, as described above, it is desirable to systematically consider the construction conditions of the embankment and the state of maintenance and maintenance in forecasting. For this reason, the items in the cross section shown in Figure 2 were read as a database for the factors considered to effective the collapse shape, that is, the embankment information shown in Table 1 as the condition for predicting the collapse shape. In addition, we selected basic information that are thought to be easy to obtain information from existing materials.

Here, the Hayashi's quantification methods is classified into several categories, but as described above, the presence or absence of damage occurrence is decided by the collapse shape rather than the deformation amount. In this case, the objective variable becomes the collapse shape and the explanatory variable predicts the collapse shape, but the collapse shape which is the objective variable is indicated as "qualitative" rather than numerical value. Therefore, in the study, analysis was carried out by Hayashi's quantification methods class II used when the objective variable is qualitative. In order to analyze qualitative data rather than numerical data, the Hayashi's quantification methods introduces dummy variables, quantifies qualitative data and performs multivariate analysis. Hayashi's quantification methods class II is a linear discriminant analysis using dummy variables.

3 PROPOSAL OF PREDICTION METHOD

The results of analysis by Hayashi's quantification methods class II are shown below. Table 2 shows the relationship between the collapse shapes (objective variable) obtained from the analysis result and the center of gravity of the axis. According to this, the axis 1 is different from the collapse shape II and others, the axis 2 is divided into the collapse shape I and others.

Table 2. Relationship between collapse shape and center of gravity of axis

Collapse shape	Center of gravity of the axis	
	Axis 1	Axis 2
Type I	−0.027	−1.795
Type II	0.578	0.197
Type III	−1.024	0.214

Axis 1 is defined as an influencing factor of collapse shape II, and axis 2 is defined as an influencing factor other than collapse shape I. Therefore, when the axis 1 is a positive number, the influence factor of the evaluation of the collapse shape II is high, and when the axis 2 is a positive number, it indicates that the influence factor of the evaluation other than the collapse shape I is high.

Figure 3 shows the category score. According to this, from the score of axis 1, when the elapsed years are located in the valley bottom plain for more than 50 years, it shows that the influence on the collapse shape II is large and the influence of the rainfall/seepage water is small. From the score of axis 2, it is located in the valley plain and lowland, and when the material is soil type III and the height is 15 m or more, it shows a large influence on the collapse shape I.

In addition, Figure 4 shows the relationship between explanatory variables and ranges of category scores. Also from this figure, it is clear that the topographic and the elapsed years after construction in the collapse shape II (axis 1), the topography condition, the embankment height and the embankment material are large in the collapse shape I (axis 2), which has a large influence on the predicted value.

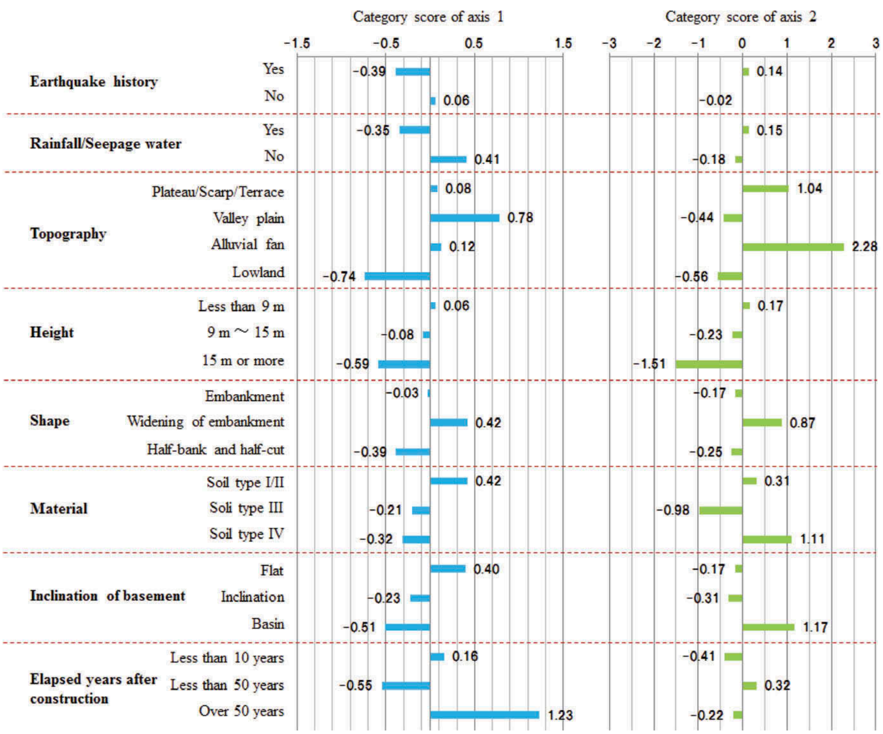

Figure 3. Category score

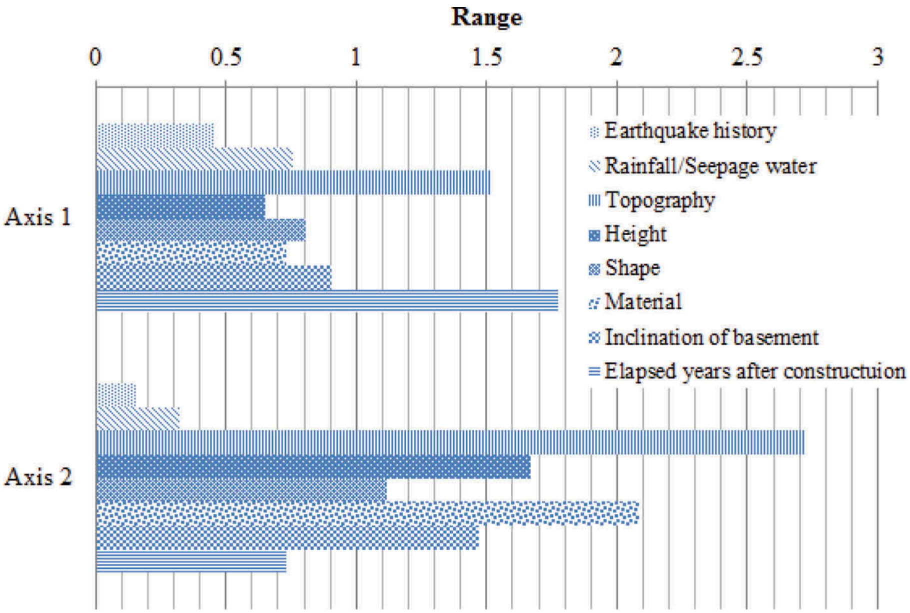

Figure 4. Relationship between explanatory variable and range

Figure 5 shows a scatter plot of sample scores for each collapse shape. The scatter plot show which sample score obtained from the analysis result is close to the center of gravity of the collapsed shape. In the analysis result this time, the correlation ratio between the sample score and axis 1 was 0.53, the axis 2 was 0.36, and the discriminative predictive value was 85%.

Therefore, according to the category score obtained in this study, the score is calculated using the condition read from the embankment information, and which score of the collapse shape in the figure the score calculated using the scatter chart of the score is calculated it is possible to predict the shape of the collapse at the time of the earthquake.

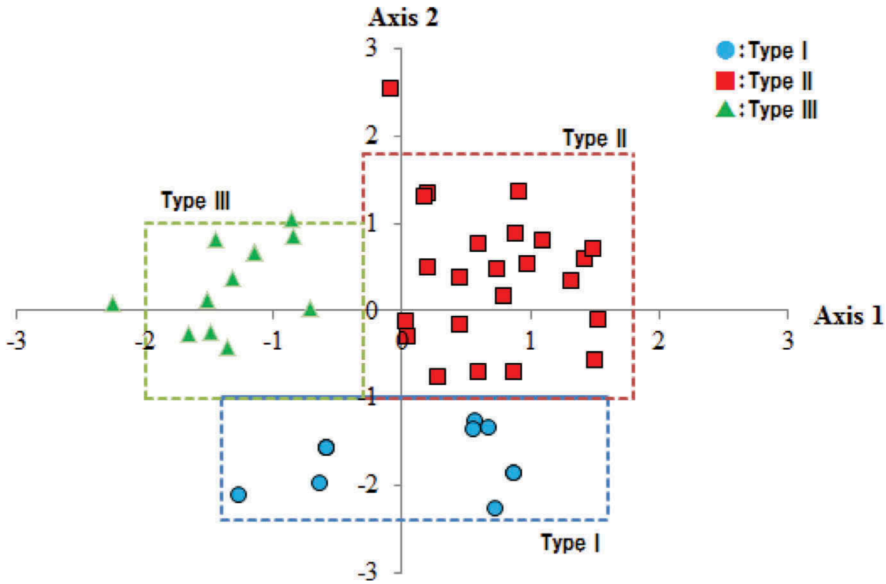

Figure 5. Scatter plot of sample score

4 VERIFICATION BY EMBANKMENT DAMAGE CASE IN TOHOKU REGION PACIFIC COAST EARTHQUAKE

For the conventional line embankment affected by the Tohoku Region Pacific Coast Earthquake, we calculate the score using the category score obtained in the previous study, compare the collapse shape obtained from the score discrimination standard with the actual damage situation. We conducted verification of the examined prediction method. In the previous studies, we have not used the record of the conventional line embankment damaged by the Tohoku Region Pacific Coast Earthquake.

The damage of the conventional line embankment in the Tohoku Region Pacific Coast Earthquake has been confirmed over a wide area from the northern part of Miyagi prefecture to the eastern part of Chiba Prefecture, but it is characterized by the fact that the number of large-scale afflicted sites was small compared to the past earthquake. This is as small as 16mm at the site where the total rainfall before the earthquake is large, and it is considered as one factor because it is not influenced by rainfall before the earthquake as pointed out so far. However, it is suggested that influence of infiltration water is pointed out in most of the typical emergency embankment, and it is influenced by water such as groundwater as well as rainfall, JR East (2011).

Among them, the section between Nitta and Ishikoshi in the Tohoku Line was a double track in 1952, but the embankment with a height of 5m of the uploaded line which had been used before that collapsed over 50m in the direction of the railway track. As shown in Figure 6 (1), it is assumed that the sliding fracture of the embankment is assumed, so the collapse shape is considered to be type II. Also, as for the interval between Sakunami and Okushinkawa on Senzan Line, the embankment (17m high on the valley side and 9m high on the mountain side) on the sloping ground plate located in the catchment topography collapsed over 50m in the track direction, As shown in 2), JR East (2011), it is thought that the sliding failure of the embankment is similar to the collapse shape in the same way as the type II.

For Umegazawa - Nita between the Tohoku Line, as shown in Figure 7(1), embankments with a height of 8m in the section where the extension work of the railway was completed in 1964 broke down 100m in the direction of the railroad track. In this section, the same collapse has occurred in the Miyagi prefecture northern earthquake that occurred in 1964. The influence of the humus soil layer intervening in the supporting ground is pointed out as a cause of collapse, and the collapse shape is considered to be type III. Also, for the Aziki-Kobayashi route between Narita Line, as shown in Figure 7(2), the embankment height of 4m sank down by about 1 m over the line extension 120m. Sand spray is confirmed in the buttocks of this section, and liquefaction of the fine sand layer deeper than about 4 m from the ground surface has been pointed out, JR East (2011). It is speculated that the embankment subsided due to this influence, and the collapse shape of this section is considered to be type III.

(1)Tohoku Line Nitta-Ishikoshi (2)Senzan Line Sakunami-Okushikawa

Figure 6. Type II situation, JR East (2011)

(1)Tohoku Line Umegasawa-Nitta (2)Narita Line Aziki-Kobayashi

Figure 7. Type III situation, JR East (2011)

With respect to the damage situation of the embankment described above, using the category data obtained from the various conditions of the embankment, the collapse shape of the embankment is predicted from the score calculated by the category score of Figure 3, a comparison was made. Figure 8 shows the result of comparing the collapse shape predicted from the obtained score with the actual damage situation. According to these, there was one case of the result of the discrimination based on the calculated score for the collapse shape I which was not found in the case of damage. However, in all other cases, it is understood that the collapsed shape which is judged to be the actual damage situation matches the collapsed shape.

In the example in which the discrimination result did not match, the extension work of the railway was implemented in 1960 and it was improved from the single-line embankment to the double-line embankment, but the new embankment part at this time, so-called widening embankment, collapsed. It is also confirmed that there is a humic soil layer on the bearing stratum, groundwater is high, and water was also present inside the embankment. For these reasons, the embankment shape of the section was considered as embankment as a factor that the damage and prediction did not match, but in reality it seems reasonable to consider it as

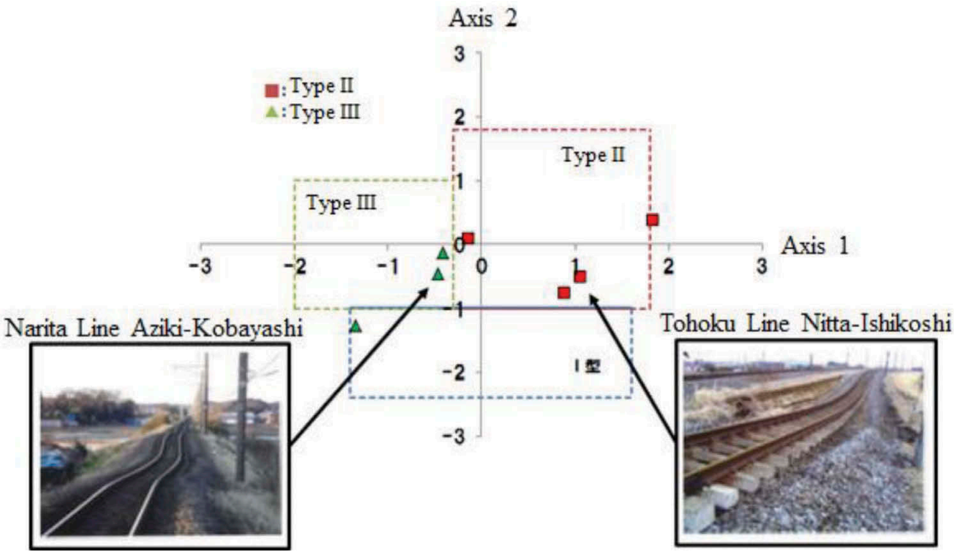

Figure 8. Relationship between score calculation result and confirmed destructive shape

an embankment. If considering it as a widening embankment, it is determined as a type III, and it is confirmed that it agrees with the actual damage situation.

This resulted in giving a challenge to calculating the score by calculating the score with the current embankment shape in the embanked category in the embankment condition for predicting the collapse shape. In other words, when there is a history such as the construction of railway lines, it is suggested that scrutiny of the circumstances such as the size of the widening embankment, the situation of the embankment before construction and the construction of the railway line.

However, for other embankments, the identified collapse shape and the actual damage situation coincide, indicating that the proposed discrimination prediction method can explain well the actual condition of earthquake damage on embankment. Here, the discriminant predictive value in the case verification described above was 86%, which confirmed that it was a high hit rate. This suggests that the proposed discrimination prediction method has sufficient accuracy even at the practical level.

5 CONCLUSIONS

It is thought that the assumption of the collapse shape was possible with a certain degree of accuracy by the discrimination method studied this time. As an example of the application of this discrimination method, for example, when it is determined that it is a collapse shape I, it can be considered that the damage is minor and the detailed seismic diagnosis and the priority of reinforcement are set low. In addition, as described above, the collapse shapes I and II are made to coincide with the collapse shape in rainfall in existing research. This is due to the fact that in the case of collapse shape I or II, it can be thought that it can be a countermeasure against earthquake resistance by implementing measures against rain. In other words, it is considered possible to perform seismic reinforcement only in the case of collapse shape III, and to judge the necessity of reinforcement with or without rain countermeasure for other cases.

However, at present it has not been verified whether it has accuracy as a discrimination prediction formula applicable in practice. In the future, we will analyze using more data, improve the accuracy of the category score, construct a simplified discriminant prediction formula applicable to practice, collect cases of no damage and check on the presence or absence of damage we also want to implement a method that can further rationally discriminate by making it possible to judge.

REFERENCES

Sugiyama, T., Mori, T., Nunokawa, O. and Ota, N. 2008. A Statistical Method to Predict the Shape and Scale of an Embankment Collapse under the Rainfall, *RTRI Report Vol.22*, *No.1*, *(in Japanese)*

Railway Technical Research Institute. 2007. Maintenance standard of railway structure (soil structure), *(in Japanese)*

Nakamura, H., Yokota, S. and Yoshimura, M. 2013.Establishing a Seismic Assessment Method for Earthquake Disaster Management of Expressway Embankments, *Journal of JSCE F4*, *Vol.69*, *No.2*, *(in Japanese)*

Nozawa, D. 1986. A Study on Earthquake-proof Reinforcement of Tokaido Shinkansen Embankment, *Railway Technical Research Report, No.1304, (in Japanese)*

Sugiyama, T. 1997. A Study on Disaster Risk Estimation for Prevention of Railway Slope Failure during Rainfall, *RTRI Report, Special No.19, (in Japanese)*

Railway Technical Research Institute. 2007. Design standard of railway structure (soil structure), *(in Japanese)*

Railway Technical Research Institute. 2012. Design standard of railway structure (seismic code), *(in Japanese)*

East Japan Railway Company. 2011. Feature article "Tohoku Region Pacific Coast Earthquake and Railway Structure", *SED, No.37, (in Japanese)*