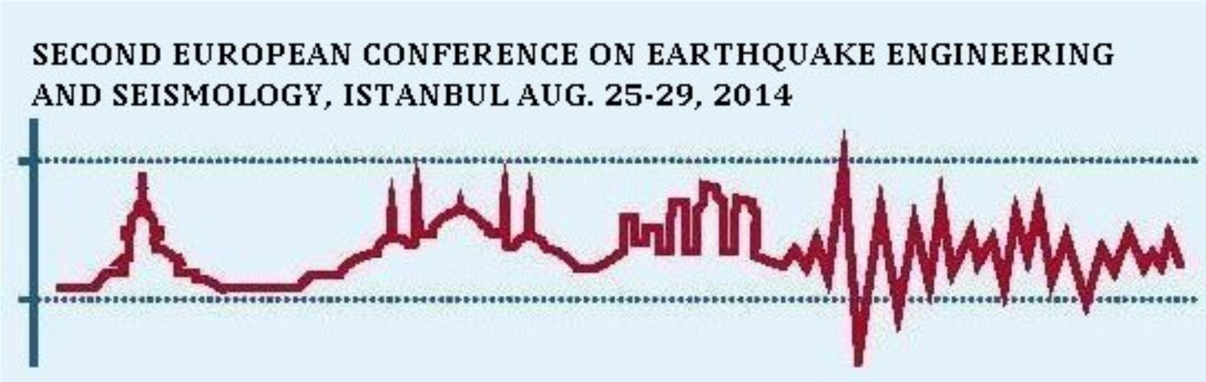


FRAGİLİTY CURVE OF THE BRİDGE MEMBER AT NATİONAL ROAD BASED ON THE DAMAGED DATA DUE TO THE 2011 OFF THE PACİFİC COAST OF TOHOKU EARTHQUAKE

Susumu NAKAMURA[1]

ABSTRACT

Based on the damage data of 819 bridges except the damage caused by tsunami among 960 bridges due to the 2011 off the Pacific coast of Tohoku Earthquake, the analysis in this report was carried out to make clear the relationship between the damage features and the structural characteristics, and the intensity of earthquake ground motion. The records obtained at 369 points observed in 6 prefectures in Tohoku region with the surrounding 4 prefectures of Niigata Prefecture, Gumma Prefecture, Tochigi Prefecture and Ibaraki Prefecture were used to estimate the intensity of earthquake ground motion such as the peak ground acceleration (PGA) and the peak ground velocity PGV by Spline interpolation method.

As a number according to the damaged element of bridge, most damaged element is level differences behind abutments. Subsequently, there is much collapse of shoe. Moreover, damage about failure of a bridge pier or abutments are few. The damage behind abutments has few differences according to bridge type. Failure of shoe has occurred in a steel bridge mostly. It is found that the damage probability of level difference behind abutments becomes more than 30% around 30 cm/s of PGV, and that the damage of shoe has the high correlation with the component of velocity of an earthquake ground motion, but that it also has relationship with acceleration.

INTRODUCTION

Many infrastructures suffered a great deal of damage according to the 2011 off the Pacific coast of Tohoku Earthquake which occurred on March 11, 2011. Road networks, such as a highway and a national road, have the important role for restoration etc. Although serious damage such as a collapse of bridge has not occurred, it will have significant influence not only on restoration but also on a social activity in local area by traffic restriction for repair and reinforcement, etc. In order to evaluate the feature of damage synthetically and quantitatively, it becomes useful to analyze the fragility characteristic of damage. Furthermore, in the viewpoint of not only the prevention from a huge earthquake but also the correspondence of restoration after an earthquake, the obtained fragility characteristic can be used for the assessment of damage against a possible huge earthquake. Here, the fragility characteristics about the some bridge members are evaluated for the bridge damage of a national road.

The damaged bridge among the national roads which located in Iwate Prefecture, Miyagi Prefecture, and Fukushima prefecture reaches 960. First of all, the damage situation of a bridge is described (WG 1 of Joint Committee in Tohoku branch of 7 Japan Society about the Great East Japan Earthquake;2013). Although the damage situation of the bridge including the influence by tsunami is

[1] Professor, Nihon University, Koriyama Japan 963-8642, s-nak@civil.ce.nihon-u.ac.jp

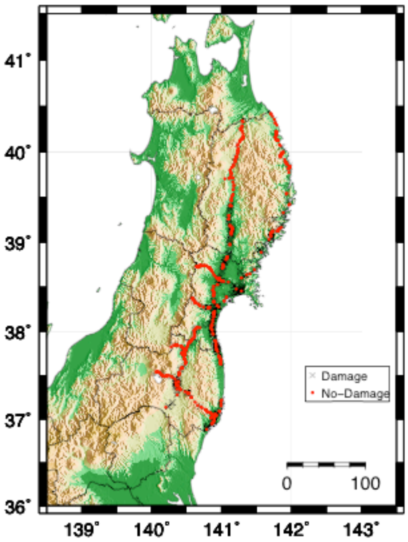


Figure 1. Locations of 960 damaged bridges and no damage


Photograph 1. Example of collapsed pier of Utatsu bridge at route 45 of the national road

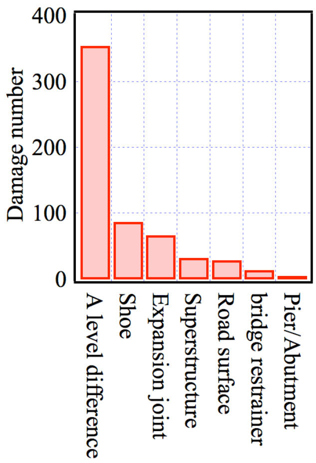


Figure 2. Comparizon of damage number according to major element of bridge

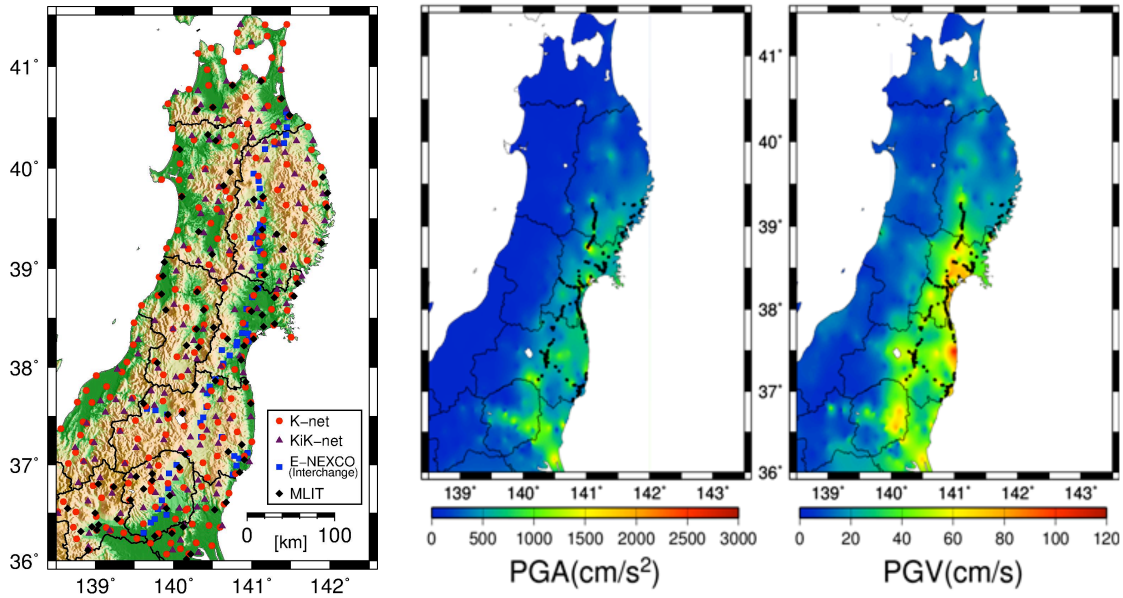

a) Samegawa bridge
b) Shakadogawa bridge
Photograph 2. Examples of damage such as level difference and collapse of shoe

described, the bridges damaged by earthquake ground motions except tsunami were considered as the object of examination. Next, the intensity of earthquake ground motion at the locations of the damaged bridges was estimated by being interpolated spatially based on the existing observed records. Furthermore, in order to clarify the structural feature of the damaged bridge, a damaged member, the bridge type, the age of design criteria, etc were analyzed. At the last, the fragility curves about some major damaged elements are evaluated.

DAMAGE OUTLINE ABOUT BRIDGE OF A NATIONAL ROAD

The locations of 960 damaged bridges among bridges of the national roads located in Iwate Prefecture, Miyagi Prefecture, and Fukushima Prefecture are shown in Figure 1. Among the damaged bridges, the damaged bridges due to tsunami were 141. The serious damage such as collapse of bridge pier occurred. As a example, collapsed pier of Utatsu bridge at route 45 of the national road was shown in Photograph 1.

The analysis in this report was carried out for 819 bridges except the damage caused by tsunami among 960 bridges. First, comparison of the damaged number according to major element of the bridge is shown in Figure 2. It is found that a level difference by subsidence behind abutments of a



a)Arrengement of seismic observation points for each organaization

b) Spatial distribution of each intensity of earthquake ground motion

Figure 3. Spatial distribution of PGV and PGA which estimated in northeast 6 prefectures and the surrounding prefectures by space interpolation and the arrangement of the observation points

bridge is the largest number among the damaged elements. As the example of the level difference, the damage which occurred at the Samegawa bridge located in the National Route 6 in Fukushima Prefecture is shown in Photograph 2a). Subsequently, many shoe damages have occurred. The shoe damages have occurred irrespective of kinds of shoe, such as BP bearing, rubber shoe, and cast iron shoe. As a damage example of cast iron shoe, collapse of shoe at Shakadogawa bridge located in the National Route 4 of Fukushima Prefecture is shown in Photograph 2b). On the other hand, it is a feature that the damage number of a bridge pier and an abutment is little with six. Therefore, by paying attention to the damage of not only a level differenece behind abutments but also a collapse of shoe, the relationship between the structural characteristic and the intensity of earthquake ground motion is evaluated. Furthermore, the relationship between damage probabilities of those and the intensity of earthquake ground motion is also evaluated.

CHARACTERISTICS OF EARTHQUAKE GROUND MOTION AT DAMAGED POINTS

The intensity of earthquake ground motion at the location of damaged bridge is needed to evaluate the fragility characteristic. The ground condition is necessary for evaluating the intensity at the location by dynamic response analysis based on numerical method. However, it is difficult to get individually the information of ground condition at every location. Therefore, the intensity of earthquake ground motion at each location of damaged bridge was estimated as the approximate value based on the space interpolation by using spline interpolation from the intensities of the observed earthquake ground motion around the damaged point. Maximum acceleration PGA and the maximal rate PGV were used as intensity of earthquake ground motion among various intensity indices which have influence on the collapse of bridge.

Moreover,as seismic observation records which used for the spatial interpolation, the seismic records observed by 61 ICs in the network of expressways of E-NEXCO were first used. Furthermore, the records obtained at 369 points observed in 6 prefectures in Tohoku region with the surrounding 4 prefectures of Niigata Prefecture, Gumma Prefecture, Tochigi Prefecture and Ibaraki Prefecture among the observed records by kyoshin network (K-net) and Kiban kyoshin network (kik-net) were used. Those networks were installed by National Research Institute for Earth Science and Disaster Prevention. In addition to these, the records observed at 87 facilities exhibited by the Ministry of Land,

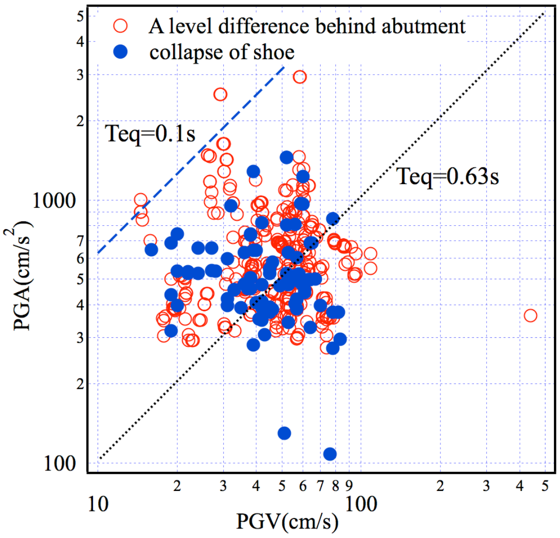


Figure 4. Relationship between PGA and PGV at damaged bridge

Table 1. Relation between a damage of level differenece behind abutments and the standard based when designing

Revised year of standard		Number of damaged bridge
Before 1963		69
1964	(1964-1974)	88
(1975)	(1975-1989)	55
(1990)	(1990-1993)	7
1994	(1994-1995)	7
1996	(1996-2011)	31

Infrastructure, Transport and Tourism were used. The spatial distribution of PGV and PGA which estimated in northeast 6 prefectures and the surrounding prefectures by space interpolation and the arrangement of the observation points are shown in Figure 3.

The relationship between PGA and PGV which estimated at the location of damaged bridge according to not only the level difference behind the abutment but also collapse of shoe including collapse of shoe support is shown in Figure 4. Both damages have caused from comparatively small PGA and PGV. It is found that the damages of the level difference behind the abutments have generated by the earthquake ground motion which has a frequency characteristic whose equivalent predominant period (=2 π PGV/PGA) is longer than about 0.1 second.

RERATION BETWEEN DAMAGES ACCORDING TO ELEMENT OF BRIDGE AND INTENSITY OF EARTHQUAKE GROUND MOTION AND STRUCTURAL CHARACTERISTICS

As for the damage of not only the level difference behind the abutment but also collapse of shoe with collapse of shoe support, the relationship with the intensity PGA and PGV of earthquake ground motion was analyzed as well as the structural characteristics such as the kind of bridge, a bridge length, and the japanese standard based when designing.

Analysis of the damage of a level differenece behind abutments

First of all, the relation between a damage of level differenece behind abutments and the japanese standard based when designing is shown in Table 1. Revison history in Japan acording to the design method of shoe is described as follows.The design consideration about the ground behind abutments was prescribed for the first time by the substructure design standard of road bridge in 1964. The regulation was descreibed as structural details. Although the sufficient compaction is required to construct the ground, it was described to be unavoidable to subside a little. Furthermore, when paving immediately after construction of back banking, the points of concern, such as preparing the approach slab in the abutments and easing the action on abutments according to not only vehicles but also subsidence, were specified. On the revision of structure details by substructure design standard of road bridge in 1975, although the points of concern about drainage were added, the fundamental view was the same as the 1964 standard. On the revision in 1990 and 1994, the contents are the same as 1975 standard. The consideration to the influence by an earthquake was specified for the first time by revision of the 1996 standard after the Hyogoken Nanbu Earthquake in 1995. Since subsidence by shaking and liquefaction due to an earthquake may have caused, it was specified that the installation of the approach slab was desirable. Among the damaged bridges, although bridges designed by the 1994

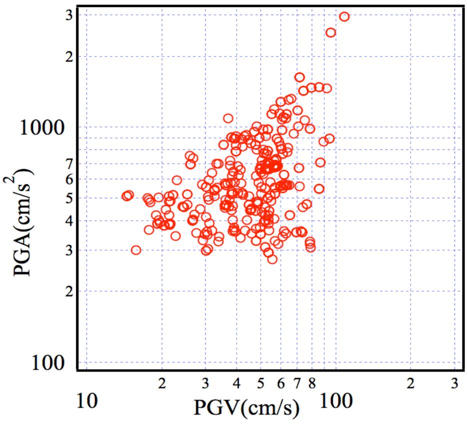


Figure 5. Relationship between PGA and PGV at the bridge with a level difference

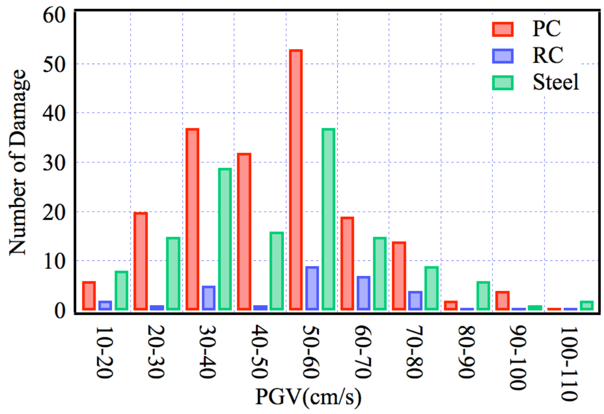


Figure 6. Relation between PGV and the damage number according to the kind of bridge

Table 2. Relation between a damage of shoe and standard based when designing

Revised year of standard		Number of damaged bridge
Before 1955		2
1956	(1956-1963)	10
1964	(1964-1963)	20
1972	(1972-1977)	11
1980	(1972-1979)	15
1983	(1980-1982)	1
1993	(1993-)	7

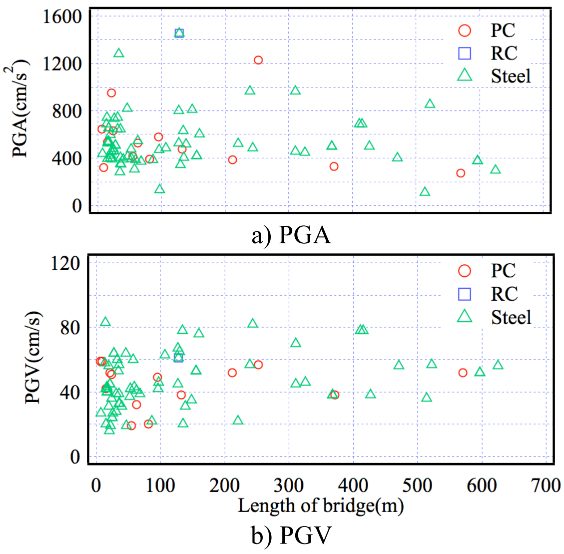


Figure 7. Relationship between PGA, PGV at the bridge with damaged shoe and the structural characteristics, such as the kind of bridge and bridge length

previous standards are many, the bridges by the latest standard are also included. A difference was not observed in the intensity of the earthquake ground motion according to the age of the standard by which the damaged bridge was designed.

Next, the relationship between the intensity PGA and PGV of earthquake ground motion at the bridge with a level difference behind abutments and the structural characteristics are shown in Figure 5. It is found that damage has appeared in the remarkable small earthquake ground motion, and that the damage number has increased with the increase in PGV. The relation between PGV and the damage number according to the kind of bridge is shown in Figure 6. The damage about the bridge of PC and RC is slightly large compared with the damage about a steel bridge, and the clear relation with the kind of bridge is not found. Moreover, many damages were caused against PGV in the wide range from 30 cm/s to 70 cm/s.

Analysis of the damage of shoe

First of all, the relation between a damage of shoe and the japanese standard based when designing is shown in Table 6. Revison history in Japan acording to the design method of shoe is described as follows. Details regulation was prepared at first in specification of steel road bridge design in 1956. The design of a shoe part was revised in 1964, and new use steel materials including cast iron were added. Furthermore, the seismic resistance design standard of road bridge antiearthquake was published in 1972, and not producing collapse of bridge as an seismic performance required of shoe during earthquake was specified clearly. structure details including seimic load were also specified.

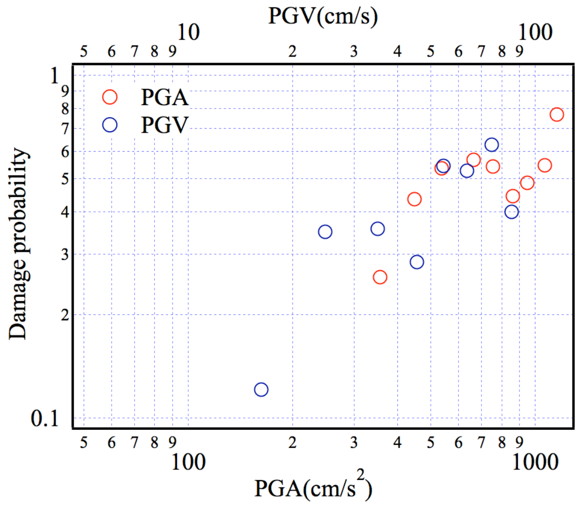


Figure 8. Relationship between damage probability about the level difference behind abutments, and the intensity PGA and PGV

Table 3. Relationship between average intensity in every intensity interval, the number of damaged bridges, and the number of non-damage bridges

a) PGA

Average PGA (Gal)	Number of damage	Number of non-damage
150.6	0	77
275.7	7	70
357.0	60	173
448.3	66	86
536.2	67	58
662.6	52	40
754.2	26	22
860.6	24	30
947.0	17	18
1063.4	6	5
1153.3	10	3

b) PGV

Average PGV (Gal)	Number of damage	Number of non damage
8.1	0	8
16.2	16	116
24.8	36	67
35.1	71	128
45.6	49	123
54.3	99	83
63.4	41	37
74.8	27	16
85.4	8	12
(94.9)	5	1
(105.6)	2	1

When the 1978 Miyagi-ken-oki earthquakes occurred, the most damaged shoes were designed by the standard revised before 1964. Revision of specification in 1980 was carried out based on the results of an investigation of e the 1978 Miyagi-ken-oki earthquakes. It is found that the many bridges with damaged shoe were designed especially based on the standard in 1956 and 1980 before the 1980s.

Next, the relationship between the intensity of earthquake ground motion at the bridge with damaged shoe and the structural characteristics, such as the kind of bridge and bridge length, is shown in Figure 7. It is found that many damages of shoe have occurred in the steel bridge. The tendency about the kind of damaged bridge is different from that according to the level difference behind abutments. It is considered that a steel bridge with lightweight had been used because many wide rivers such as Abukuma river, the Kitakami river, etc. exist in Tohoku region. Moreover, for the bridge with length longer than 100 m, The damage number of shoe has the tendency to increase against small PGA as bridge length becomes long. It is estimated to be caused because the inertia force which acts to a shoe increases as bridge length becomes long.

DAMAGE PROBABILITY FOR MAJOR DAMAGED ELEMENT

First, the relation between damage probability about the level difference behind abutments, and the intensity of earthquake ground motions such as PGA and PGV is shown in Figure 8. The damage probability in certain intensity interval of earthquake ground motion was defined as the ratio between the number of the damaged bridges and the sum of the number of the damaged bridges and the number of non-damage bridges. Furthermore, the intensity was taken as the average value of the intensities at these bridge locations in the intensity interval. The average intensity of earthquake ground motion in every intensity interval, the number of damaged bridges, and the number of non-damage bridges are shown in Table 3. As for PGA, damage probability increases from 300Gal to 600Gal as PGA increases, but damage probability becomes constant value to PGA beyond 600Gal. On the other hand, as for PGV, although sufficient correlation for the increase in damage probability and PGV is not accepted, damage probability increases in the wide PGV range of 20 cm/s to 70 cm/s. Based on not only the relation in the wide PGV range but also the damage which was caused by subsidence of the ground behind abutments, it will be thought that the level difference damage behind abutments has correlativity with the component of velocity of an earthquake ground motion.

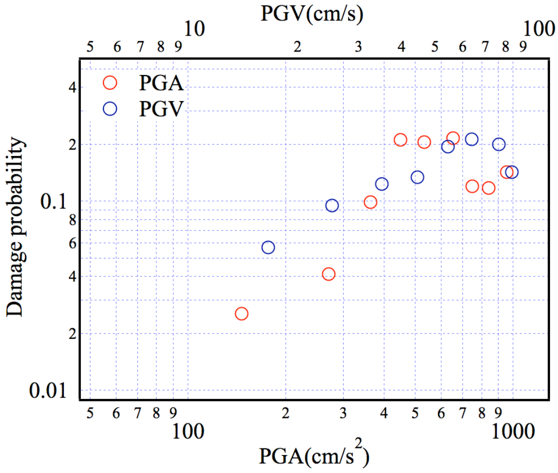


Figure 9. Relationship between damage probability about collapse of shoe, and the intensity PGA and PGV

Table 4. Relationship between average intensity in every intensity interval, the number of damaged bridges, and the number of non-damage bridges

a) PGA

Average PGA (Gal)	Number of damage	Number of non-damage
69.1	0	2
146.1	2	77
271.2	3	70
363.4	19	173
450.9	23	86
532.9	15	58
654.1	11	40
749.7	3	22
841	4	30
953.7	3	18

b) PGV

Average PGV(Gal)	Number of damage	Number of no damage
8.1	0	8
16.4	7	116
25.1	7	67
35	18	128
44.4	19	123
54.5	20	83
63.8	10	37
76.4	4	16
83.4	2	12

Next, the relation between damage probability about shoe, and the intensity of earthquake ground motions such as PGA and PGV is shown in Figure 9. Here, the definition of damage probability and the average intensity in the intensity intervals is the same as the level difference damage behind abutments. The average intensity of earthquake ground motion in every intensity interval, the number of damaged bridges, and the number of non-damage bridges are shown in Table 4. The damage probability decreases at PGA for more than 700 Gal and PGV for more than 70 cm/s. As for intensity smaller than those values, a damage probability increases as PGA increases from 300 Gal to 500 Gal. As for PGV, as PGV increases, a damage probability increases in the wide PGV range between 20 cm/s and 70 cm/s. It is found that the damage of shoe has the high correlation with the component of velocity of an earthquake ground motion, but that it also has relationship with acceleration. It is thought that this is related to a relation with the type of shoe.

CONCLUSIONS

Based on the damages of 819 bridges except the damage caused by tsunami among 960 bridges due to the 2011 off the Pacific coast of Tohoku Earthquake, the analysis in this report was carried out in to make clear the relationship between the damage features and the structural characteristics, and the intensity of earthquake ground motion.

As a number according to the damaged element of bridge, most damaged element is level differences behind abutments. Subsequently, there is much collapse of shoe. Moreover, damage about failure of a bridge pier or abutments is few.

The damage behind abutments has few differences according to bridge type. Among the damaged bridges, although bridges designed by the 1980 previous standards are many, the bridges by the latest standard are also included. The damage probability becomes more than 30% around 30 cm/s of PGV, and has the tendency that damage probability increases with the increase of PGV.

Failure of shoe has occurred in a steel bridge mostly. Moreover, the tendency is found that the damage of shoe increases against small PGA in the bridges whose length is longer than 100 m. Moreover, there were many disaster numbers of the bridge built by the old former standard in the 1980s. Bridges designed by the 1980 previous standards are also many as well as the level difference behind abutments. It is found that the damage of shoe has the high correlation with the component of velocity of an earthquake ground motion, but that it also has relationship with acceleration.

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