Cut slope damage of expressway caused by heavy rainfall in Tohoku district, Japan

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ABSTRACT

Risk assessment of cut slopes on expressways attributed to heavy rainfall is required to maintain the expressway. Firstly, damage data for 25 years (1992-2017) are introduced from the viewpoints of the property of slopes. Secondary, this study has analyzed the rainfall patterns which is one of the causes of slope damage in order to establish the risk assessment method of expressway slopes. Hourly rainfall data was prepared by linear interpolation of rainfall data from three AMEDAS points adjoining to the objective place. Each rainfall event was determined when no rain condition had lasted for 6 or 12 hours. It was shown that 12 hours is better as criteria than 6 hours for determination of rain event and the spatial variation along the expressway are discussed.

Keywords: Rainfall disaster; Precipitation; Spatial variation; Cut slope damage

1 INTRODUCTION

Maintenance and operation against heavy rainfall are important issues on cut and embankment slopes of expressways. The Japanese Geotechnical Society proposes the necessity to take the countermeasures and to plan the corresponding to the project for the purpose of decrease the road closing time effectively [1]. In order to prevent the damage of these slopes due to rainfall, risk assessment based on the predisposition such as geology, topography and in-service period and the causes such as the amount of rainfall, rainfall intensity and earthquake motion is required. However, the risk assessment method is still not established. Therefore, in this study, the authors analyzed the rainfall patterns that one of the major predispositions with using the case of slope failure which had induced the damage, in the past, on the expressways cut slopes in Tohoku district, Japan. In addition to this, the relationship between the rainfall patterns and the occurrence of damage on the cut slopes were evaluated.

2 ANALYSIS METHOD OF DAMAGE OCCURRENCE

There are 83 (during 17 years and 10 months from August 27, 1993 to June 24, 2011) and 85 (during 17 years and 6 months from February 7, 1993 to July 30, 2011) damaged cases of cut and embankment slopes respectively on expressway slopes in Tohoku district. The damage on the cut slopes has been often found directly by vehicles passing through the expressway, and there was short time lag between the occurrence and discovery of failure. On the other hand, the damage on the embankment slopes cannot be found directly from the passing vehicles, so there is a high possibility that the damage time and the discovery time do not coincide. For this reason, we analyzed the rainfall patterns by focusing cut slopes in this study. As shown in Fig.1, most damage occurred during summer season; 25 cases in July, 29 cases in August, and 22 cases in September out of 85 cases of cut slope damages. So, seasonal influence such as snow melting is small. From this, we analyzed 24 cases (12 cases each) which had been damaged by Typhoon No.4 formed in August 1998 and Typhoon No.6 formed in June 2002. A scheme of damaged places during Typhoon No.4 in 1998 and Typhoon No.6 in 2002 are listed in Table 1 and 2, respectively. In Table 2, the longitude and latitude of the damaged slopes No.15, No.16 and No.60 cannot be specified. Therefore, nine cases excluding these three points were used for the analysis.

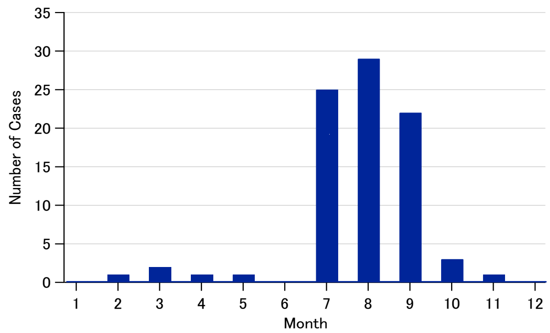

Fig.1. Distribution of occurrence timing of cut slope damages.

Table 1. List of damaged slopes by Typhoon No.4, 1998.

Slope Number	Route Name	Opening Year	In-service Period	AMEDAS 1		AMEDAS 2		AMEDAS 3	
				Point Name	Distance (km)	Point Name	Distance (km)	Point Name	Distance (km)
71	Tohoku Expressway	1973	25	Shirakawa	8.6	Naganuma	11.8	Ishikawa	20.1
49		1975	23	Yanagawa	8.1	Moniwa	9.1	Fukushima	10.3
48			23	Yanagawa	9.3	Moniwa	8.7	Fukushima	8.5
44			23	Nihonmatsu	6.1	Fukushima	10.2	Washikura	19.2
87	Ban-etsu Expressway		23	Funabiki	10.8	Koriyama	17.5	Nihonmatsu	14.6
53		1995	3	Koriyama	11.7	Funehiki	18.1	Nihonmatsu	12.1
11			3	Funehiki	13.2	Koriyama	15.4	Nihonmatsu	13.4
84			3	Funehiki	3.1	Ononimachi	15.1	Nihonmatsu	19.1
83			3	Funehiki	2.5	Ononimachi	13.0	Koriyama	26.3
46			3	Funehiki	6.3	Ononimachi	7.9	Kawauchi	23.1
86			3	Funehiki	4.9	Nihonmatsu	17.3	Koriyama	23.3
47			3	Funehiki	14.1	Koriyama	14.6	Nihonmatsu	13.0

Table 2. List of damaged slopes by Typhoon No.6, 2002.

Slope Number	Route Name	Opening Year	In-service Period	AMEDAS 1		AMEDAS 2		AMEDAS 3	
				Point Name	Distance (km)	Point Name	Distance (km)	Point Name	Distance (km)
54	Tohoku Expressway	1973	29	Koriyama	1.6	Naganuma	13.1	Tamakawa	15.7
55			29	Zao	2.3	Shiroishi	11.5	Watari	20.0
25			29	Tamakawa	13.2	Naganuma	12.1	Shirakawa	12.6
88		1975	27	Moniwa	8.2	Koromogawa	10.2	Fukushima	7.6
41			27	Yanagawa	5.8	Moniwa	11.9	Shiroishi	13.6
51			27	Yanagawa	5.2	Shiroishi	9.8	Moniwa	16.1
29		1978	24	Koromogawa	6.8	Ichinoseki	6.7	Daito	23.1
75	Yamagata Expressway	1988	14	Zao	2.9	Nikkawa	13.3	Iwanuma	23.1
60	Ban-etsu Expressway	1992	10						
8	Joban Expressway	1999	3	Hirono	8.2	Taira	12.5	–	–
15	North Sendai Expressway	2002	0						
16			0						

For the estimation of the rainfall data of the target slope, linear interpolation method of the hourly rainfall data at the nearest three AMEDAS observatories surrounding the target slope was utilized [2]. Linear interpolation was performed based on the distance of a straight line between the target slope and observatories. Specifically, as shown in Fig.2, the hourly rainfalls at each AMEDAS observatory are connected to form a three-dimensional plane, and the length of the perpendicular line drawn from the target slope to the plane was taken as the estimated hourly rainfall data of the target slope. If the hourly rainfall data at any AMEDAS observatory is lacking, the average value of hourly rainfalls at the other two points or one point was used as the rainfall data of the affected slope. Also, because the affected slope No.8 damaged during Typhoon No.6 in 2002 was located in a place close to the sea and there was no third AMEDAS observatory surrounding the site, the mean value of the hourly rainfall at the nearest two AMEDAS observatories was used for the analysis. Based on the linear interpolated rainfall data, rainfall events were determined using two conditions, one is the continuation of rainfall amount of 0 mm/hour (i.e. no rainfall) for more than 6 hours, which is currently used as a criterion for traffic regulations on expressways. The other is when no rainfall lasts for more than 12 hours. First, four rainfall events were compared in the past five years from the damage detection time. One is the rainfall event including the time of damage detection. The others are the rainfall events of top 3 cumulative rainfall except the event which damage was detected. Then the range to extract the rainfall events was expanded from the start of service until the end of 2016, and all the rainfall events that cumulative rainfall exceeded 100mm were compared.

3 RESULT OF ANALYSIS

3.1 Typhoon No.4, 1998

Due to the influence of Typhoon No.4 that occurred on August 25, 1998, there was damage of 12 cut slopes in Ban-etsu and Tohoku expressways in Fukushima prefecture. Fig.3 shows the time history of cumulative

Fig.2. Estimation of rainfall data of target slope

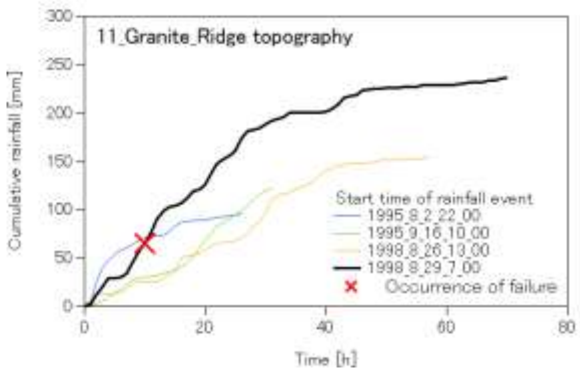

Fig.3. Cumulative rainfall delimited by 6 hours at the slope No.11

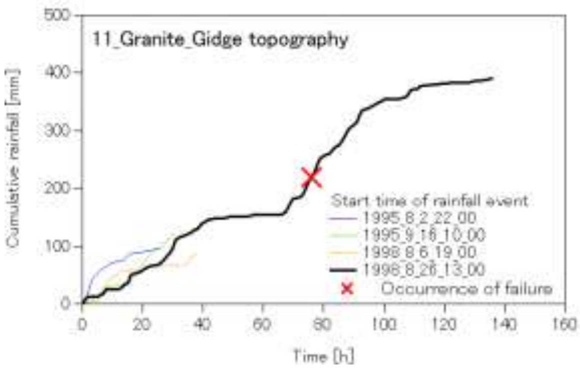

Fig.4. Cumulative rainfall delimited by 12 hours at the slope No.11

rainfall from the start of the rainfall under the condition that rainfall events were delimited by the time when no rainfall lasted more than 6 hours. These date and time on the graph indicate the start time of each rainfall event. This indicates an example of the result that the cumulative rainfall at the time of damage discovery is less than the maximum cumulative rainfall in the past five years. There were 3 similar cases out of 12 cases. From the results, it can be confirmed that two rainfall events are considered to be the influence of Typhoon No.4, from August 26 and August 31 in 1998. On the other hand, Fig.4 shows the time history of cumulative rainfall under the condition that rainfall events were delimited by the time when no rainfall lasted more than 12 hours at the same slope. Rainfall events from August 26, 1998 are combined into one rainfall event, and the cumulative rainfall at the time of the damage discovery has become the maximum value in the past five years. Based on this, it was concluded that the criteria of no rainfall of 12 hours is proper than 6 hours to delimit the rainfall event. So, here after, the data has been analyzed under the condition that the event is delimited when no rainfall lasts for more than 12 hours.

3.2 Typhoon No.6, 2002

Damages occurred on 12 cut slopes on expressways due to the influence of Typhoon No.6 born in June 29, 2002. Fig.5 shows examples that represent the time-cumulative rainfall of all rainfall events exceeding the amount of cumulative rainfall of 100 mm that occurred

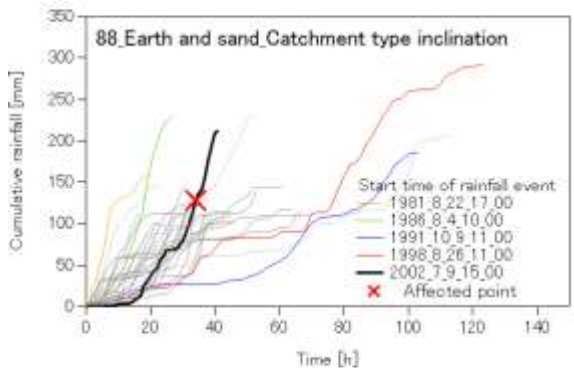

Fig.5. Cumulative rainfall at the slope No.88

from the start of service to the end of 2016 at the damaged slope. Rainfall events from the start of service to the event including the slope damage are drawn with solid lines and events after the damage to the end of 2016 are drawn with dotted lines. The event including the time when damage occurred was emphasized with black line, and the other curves drawn in orange, green, blue and red were adopted for the rainfall events indicating either large cumulative rainfall or high rainfall intensity respectively. It can be confirmed that the amount of cumulative rainfall of the event on which damage occurred was less than the maximum amount of cumulative rainfall experienced in the past. There was no clear boundary of the amount of cumulative rainfall that triggers slope failure (9 similar cases out of 12 cases). In the rainfall event that started on October 9, 1991, the total rainfall amount was as small as 11mm for 31 hours of rainfall time from 19 to 49 and for 12 hours from 73 to 84. The average hourly rainfall during these periods was less than 1mm. This is close to the criteria which delimited the event when no rainfall lasted 12 hours or more, and it can be considered practically that those can be separated into different events, respectively. The same trend was also observed during the event on August 26, 1998 in which the total rainfall amount was 11mm for 25 hours from 43 to 67.

On the other hand, the events, which show large gradient of time history of cumulative rainfall graph implying high rainfall intensity, and which occurred on August 22, 1981 and August 4, 1986, did not lead to slope failure. The reason for this may be the difference in in-service period. In general, strength reduction progresses with increase in in-service period. The events in 1981 and 1986 occurred when in-service period is quite shorter than the events on which failure occurred. Therefore, it is considered that the cut slopes in 1981 and 1986 had had higher strength than how it was the damage time.

It may not accurately reflect the characteristics of rainfall actually experienced on the target slope when rainfall data is linearly interpolated and used. Hence deviation of these data was confirmed by comparing these rainfall data before and after interpolation. Fig.6 shows the amount of cumulative rainfall at each of three AMEDAS observatories and the amount of cumulative

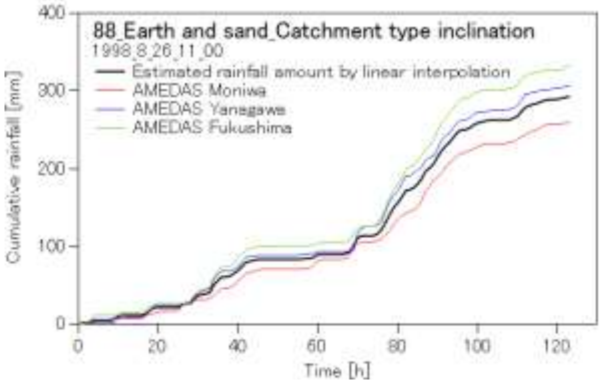

Fig.6. Comparison of cumulative rainfall before and after linear interpolation

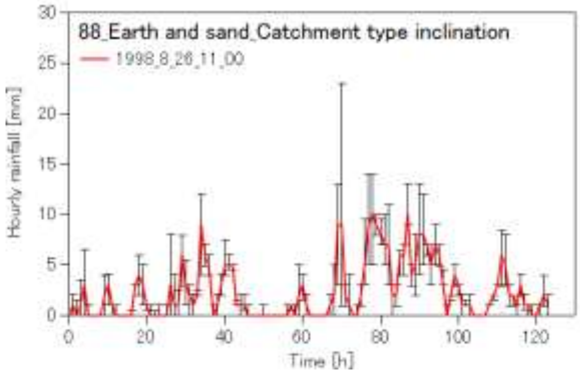

Fig.7. Comparison of hourly rainfall before and after linear interpolation

rainfall linearly interpolated with hourly rainfall at these observatories, in the event from August 26, 1998 at the slope No.88, respectively. The final cumulative value after linear interpolation in this event was 293mm. The amount of cumulative rainfall of the AMEDAS observatory in Fukushima, which was 333 mm and the highest of all, was 40 mm (14%) higher than the value obtained by the linear interpolation. On the other hand, the amount of cumulative rainfall at the AMEDAS observatory in Moniwa was 259mm (the smallest of all) and the difference from the cumulative value estimated from linear interpolation was -34mm (-12%). From this, it can be said that the deviation of estimated cumulative rainfall using neighboring AMEDAS data of the target site may become about 15%.

Linearly interpolated hourly rainfall data is represented with the maximum and minimum value of the neighboring three AMEDASs at the same event in Fig.7. In this figure, the maximum hourly rainfall was +14mm (+156%) and the minimum hourly rainfall was -8mm (-89%) at each AMEDAS observatory compared with that of linearly interpolated, at the 70h of rainfall time. It represents that the hourly rainfall at a certain time may differ about 150% from the estimated value.

From the above results, deviation of the hourly rainfall data at three AMEDAS observatories was confirmed. This result indicates that the value obtained by linear interpolation method may greatly differ from the hourly rainfall of the actual target slope. One of the causes that can be considered is that a time lag in fluctuation of rainfall data at each AMEDAS observatory exists because of the traveling time of raincloud. Another reason is the difficulty to estimate the local rainfall from the rainfall data of the AMEDAS observatories located about 20 km apart.

4 CONCLUSION

The following conclusions were obtained from this study:

1) In Tohoku district of Japan, the damage at the slope is concentrating in the summer, and there are few seasonal effects other than rainfall such as snow melting.
2) It is considered to make the end of the rainfall event when no rainfall lasts for 12 hours, and it is more appropriate than for 6 hours.
3) As the evaluation of the rainfall data at the damaged slope, the difference of the accumulated rainfall estimated by linear interpolation method from the neighboring AMEDAS data amounted to about 15% at maximum. Similarly, the difference of the hourly rainfall was about 150% at maximum.

The following items are future topics of discussion.

A) Improvement of accuracy of estimated rainfall at the target slopes:

Analytical rainfall is a precipitation distribution created from radar data and AMEDAS data. It is considered that this data is actually closer to the actual one than the rainfall estimated by the linear interpolation method used by this study. The rainfall pattern at affected slopes is to be reevaluated by using the analytical rainfall.

B) Consideration of rainfall intensity and half-life:

In addition to comparing cumulative rainfall, analysis taking into account the half-life of water content of slope and rainfall intensity are necessary.

C) Analysis of predispositions:

It is necessary to evaluate the risk by analyzing the predisposition of each slope such as geology, topography, and hydrological conditions, in addition to analyzing the rainfall as a cause. It is thought that this can be evaluated by comparison with nearby cut slopes that were not damaged.

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