A PROPOSITION ON PREDICTING EARTHQUAKE DAMAGE

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SUMMARY

This study analyzed the correlations between earthquake vibrations and their associated damage based on data from past earthquake damage in the Hokkaido and Kagoshima areas. The vibration-damage correlation was examined by statistical analysis of the effects of earthquakes based on the characteristics of the ground, and suggestions concerning damage forecasts were made as a measure for reducing earthquake damage. Statistical analysis of the vibration-damage correlation was conducted using the equation of accelerated velocity-distance damping caused by estimated earthquake vibrations and geological data on the damaged area meshes of embankments, slopes and structures. By focusing on the ground classification for the earthquakes, the damage rates were correlated using the estimated acceleration from earthquake vibrations in the damage areas.

Regarding the vibration-damage correlation of the three earthquakes in Hokkaido, satisfactory correlation was obtained in areas geographically classified as al1uvial fans and deltoid lowlands except for the unconsolidated sediment of the Diluvium epoch, which is a surface rock classification (including the surface age). Regarding the vibration-damage correlations obtained by combining data from the first and second Northwest Kagoshima Earthquakes, strong correlations were obtained in areas geographically classified as undu1ating highlands and the consolidated and semi-consolidated/consolidated sediment of the Palaeozoic and Mesozoic eras, which is a surface rock classification (including the surface age). Although a certain degree of vibration-damage correlation was obtained through geographic classification and surface rock classification, no correlation was observed between Hokkaido and Kagoshima. This was thought to be due to the unique regional characteristics of Hokkaido.

INTRODUCTION

The ability to predict the damage on road structures and others caused by earthquake vibrations is extremely important in designing earthquake-proof structures and promoting earthquake prevention measures. To forecast earthquake damage, it is necessary to accurately estimate past earthquake vibrations based on the characteristics of the ground, to measure various factors causing earthquake damage and to clarify complicated combinations of these factors. Meanwhile, it is possible to determine the impact of subsurface layers on structures by analyzing the transfer of earthquake vibrations from surface soil based on ground characteristics, which differ by region.

To analyze the correlations between earthquake vibrations and their associated damage, data on past earthquake damage in the Hokkaido and Kagoshima areas were used. The vibration-damage correlation was examined through a statistical analysis of the impact of earthquake vibrations based on ground characteristics, and suggestions concerning damage forecasts were made as measures to reduce earthquake damage.

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ANALYSIS METHOD

This study analyzed three earthquakes in Hokkaido which caused severe damage and recent earthquakes in Kagoshima. Table 1 shows their occurrence dates, scales, depths and the number of vibration-measuring points. Although the measurement direction for horizontal movements using a strong motion seismograph was different for each earthquake, the maximum value in the bridge's axial direction was used for the analyses.

Based on the data for each earthquake shown in Table 1, a forecast equation $\alpha = a \times 10^{bM} \times (\Delta + 30)^c$ was obtained through multiple regression analysis using the least squares method and by returning the equation of distance damping of the estimated earthquake vibrations based on earthquake characteristics to the equation of accelerated velocity-distance damping, which is indicated in the earthquake-proof design volume of the specification for highway bridges. Variables in this equation are magnitude (M), which expresses the earthquake scales, and the epicentral distance (•).

Table 1 Data on major earthquakes used for the analysis

Earthquakes	Dates	Times	Scales (M)	Depths (•)	Number of Points
Kushiro Offshore Earthquake	01/15/93	20:06	7.8	101	14
Southwest Hokkaido Offshore Earthquake	07/12/93	10:17	7.8	35	10
East Hokkaido Offshore Earthquake	10/04/94	22:23	8.1	30	11
Northwest Kagoshima Earthquakes	03/26/97	17:39	5.3	10	46
Second Northwest Kagoshima Earthquake	05/13/97	14:38	6.1	20	109

The data on the damaged areas were classified into embankments, slopes and structures, and examined mechanically on maps (Table 2). This study analyzed the damage focusing on the total number of damaged areas, irrespective of specific locations and the degree of damage.

Table 2 Number of damaged areas

Earthquakes	Number of damaged areas	Rate (%)	Total number of damaged areas
Kushiro Offshore Earthquake	154	32.5	474
Southwest Hokkaido Offshore Earthquake	103	21.7	
East Hokkaido Offshore Earthquake	217	45.8	
Northwest Kagoshima Earthquake	220	65.3	337
Second Northwest Kagoshima Earthquake	117	34.7	

This study used numerical map data (per mesh) published by the Geographical Survey Institute to analyze damage-causing factors based on geographical and geological characteristics of subsurface layers and surface age. These data were considered to be refined and standardized data in Japan in terms of quality, quantity and accuracy.

For correlation analysis, the equation of distance damping for acceleration estimated from each earthquake was used to calculate the estimated acceleration at all the damaged areas based on the scale of epicenters and the distance from damaged areas. Also, data on the geographic classification, surface rock classification and surface age were extracted from three-dimensional mesh codes for the damaged areas, and the total number of data points with the same geological characteristics of the damaged area meshes was calculated. Based on the total estimated acceleration in all the damaged areas, damage rates based on estimated acceleration were calculated.

In this way, it is possible to calculate vibration-damage correlation based on the geographic and geological classifications for each earthquake. Also, by comparing earthquakes in Hokkaido with those in Kagoshima, it is possible to examine the effects of regional characteristics on the vibration-damage correlation and to statistically analyze the damage in each region.

VIBRATION-DAMAGE CORRELATION

The vibration-damage correlation was analyzed by using the aforementioned equation of accelerated velocity-distance damping caused by estimated earthquake vibrations and geological data from the damaged area meshes. Also, by focusing on the ground classification of each earthquake, the damage rates were correlated using the acceleration estimated from the earthquake vibrations in the damaged areas (Figs. 1 – 4). The classification codes are shown in Table 3.

Table 3 Classification codes

geographic classification

classification	codes	geographic classification
, OP	01	undulating mountains(L)
	02	undulating mountains(M)
	03	undulating mountains(S)
	04	foot of a mountains
, OQ	05	undulating volcanoes(L)
	06	undulating volcanoes(M)
	07	undulating volcanoes(S)
	08	volcanic foot of a mountains
, OR	09	undulating highlands(L)
	10	undulating highlands(S)
	11	volcanic highlands
, OS	34	pebbles plateaus higher j
	35	pebbles plateaus medium j
	36	pebbles plateaus lower j
, OT	31	loam plateaus higher j
	32	loam plateaus medium j
	33	loam plateaus lower j
, OU	37	rock plateaus(higher j
	38	rock plateaus(medium j
	39	rock plateaus lower j
, OV	19	alluvial fans
	21	deltoid lowlands
	22	natural weir, reef
, OW	24	lake
	25	river
, XX	00	sea

surface rock classification(including the surface age)

classification		surface rock classification		codes	surface age
O	, Q	unconsolidated sediment	conglomerate, sand, clay	, P	Palaeozoic eras
	, P		sand	, Q	Mesozoic eras
	, Q		clay	, W	Jurassic periods
	, Q		peat	, V	Cretaceous periods
	, P		conglomerate	, X	Tertiary
	, Q		pyroclastic ejecta	, R	Tertiary(old)
	, P		conglomerate, sand	, S	Tertiary(new)
	, P		sand, conglomerate, clay	, U	alluvial periods
				, O	no indication
O	, Q	unconsolidated sediment	conglomerate, sand, clay	, T	Diluvium epoch
	, P		sand		
	, Q		clay		
	, Q		peat		
	, P		conglomerate		
	, Q		pyroclastic ejecta		
	, P		conglomerate, sand		
	, P		sand, conglomerate, clay		
	, S	volcanic rocks	volcanic ash	|	
	, S		loam		
O	, R	semi-consolidated/consolidated sediment	conglomerate stone	, X	Tertiary
	, R		sandstone		
	, X		peat		
	, X		sandstone, peat(alt)	, R	Tertiary(old)
	, X		sandstone, conglomerate stone		
	, X		peat		
	, X		slate		
	, X		sandstone peat(al)	, S	Tertiary(new)
	, R		porphry lithorogical rock		
	, R		lime stone		

classification		surface rock classification		codes	surface age
, OS	, R	semi-consolidated/consolidated sediment	conglomerate stone	, P	Palaeozoic eras
	, R		sandstone		
	, X		peat		
	, X		sandstone, peat(alt)	, Q	Mesozoic eras
	, X		sandstone, conglomerate stone		
	, X		peat	, W	Jurassic periods
	, X		slate		
	, X		sandstone, peat(al)	, V	Cretaceous periods
	, R		lithorogical rock		
	, R		lime stone		
, OT	, S	volcanic rocks	pumice flow sediment	|	
	, S		pyroclastic ejecta		
, OU	, T		tuff lithorogical rock		
, OV	, S		volcanic and tuff conglomerate		
, OW	, T		serpentinite lithorogical rock		
	, T		andesite lithorogical rock		
	, T		whin lithorogical rock		
	, U	plutonic rocks	diabase lithorogical rock		
	, U		porphry		
	, U		granite lithorogical rock		
	, U		gabro lithorogical rock		
	, U		serpentinite lithorogical rock		
	, V	metamorphic rock	hornfels		
, OX	, V		crystal lithorogical rock		
	, V		gneiss lithorogical rock		
, XX	OO		no indication		
, X	, XX		sea		

3.1 Vibration-damage correlation for three earthquakes in Hokkaido (Fig. 1):

A strong correlation was obtained in the geographic classification of Hokkaido. In the Kushiro Offshore Earthquake, the damage rate for alluvial fans and deltoid lowlands (Code 07) was 45%. In the Southwest Hokkaido Offshore Earthquake, that for undulating mountains (Code 01) was 47%, and that for loam plateaus (Code 05) was 52% in the East Hokkaido Offshore Earthquake.

Regarding the vibration-damage correlation of the surface rock classification (including the surface age), the highest damage rate among the three earthquakes was found to be as follows: 57% for unconsolidated sediment excluding that of the Diluvium epoch (Code 01) in the Kushiro Offshore Earthquake, 22% for volcanic rocks (lithorogical rock)/plutonic rocks (Code 08) in the Southwest Hokkaido Earthquake and 56% for unconsolidated sediment of the Diluvium epoch (Code 02) in the East Hokkaido Earthquake.

3.2 Vibration-damage correlation of the Northwest Kagoshima Earthquake (Fig. 2):

The vibration-damage correlation in Kagoshima was analyzed based on geographic classification. As a result, a high damage rate of 71% was obtained in an area geographically classified as undulating highlands (Code 01) in the Northwest Kagoshima Earthquake. As for a surface rock classification (including the surface age), a high damage rate of 48% was obtained in areas geographically classified as consolidated and semi-consolidated/consolidated sediment of the Palaeozoic and Mesozoic eras (Code 04).

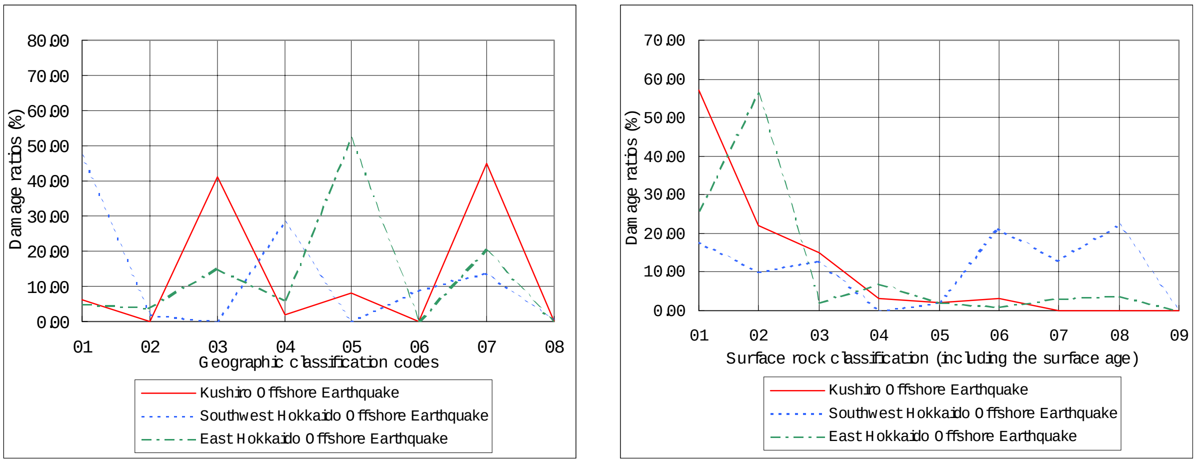


Fig.••Vibration-damage correlation in Hokkaido

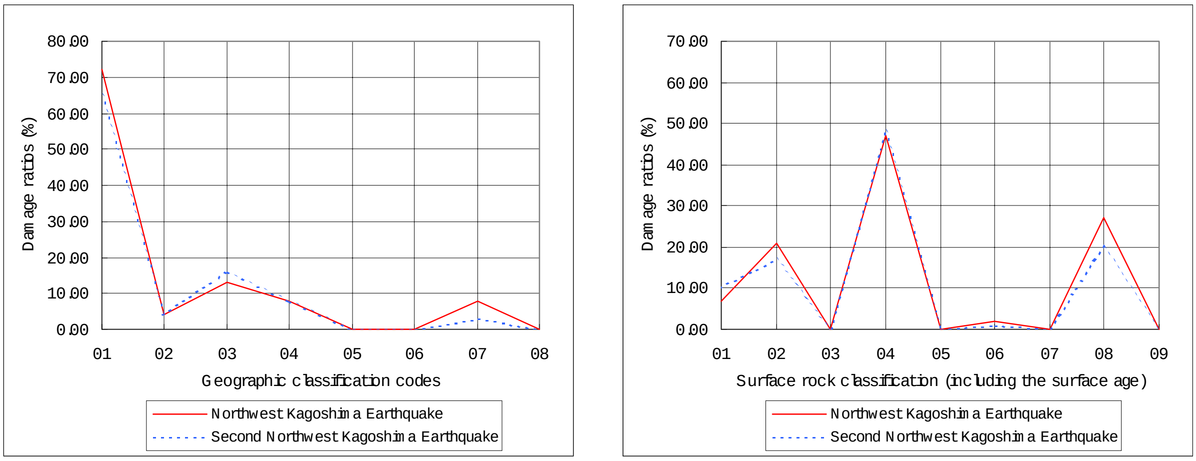
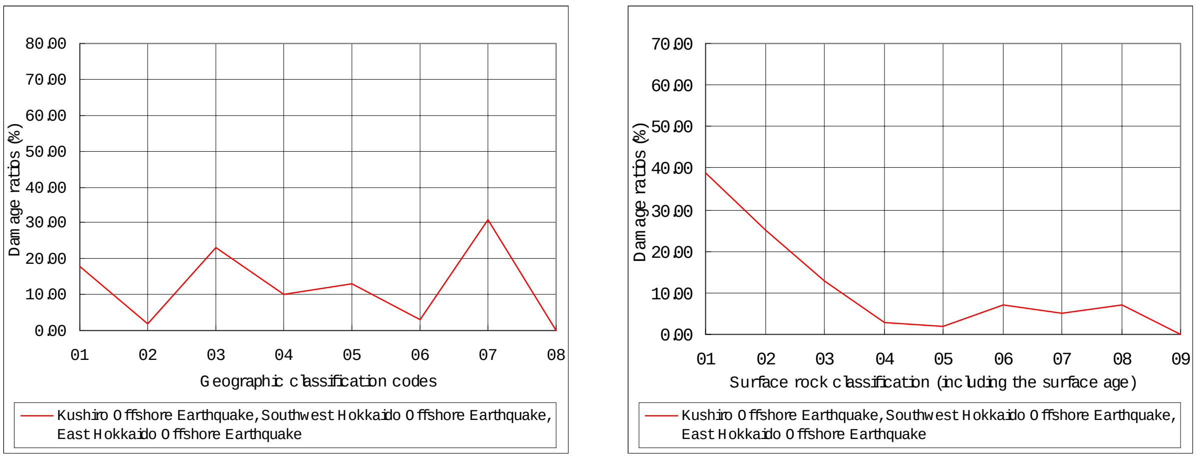


Fig. ••Vibration-damage correlation in Kagoshima

3.3 Vibration-damage correlation in Hokkaido (Fig. 3):

The vibration-damage correlation based on geographic classification and obtained by combining data from three earthquakes in Hokkaido was 31% in alluvial fans and deltoid lowlands (Code 07), and that of a surface rock classification (including the surface age) was 39% in the unconsolidated sediment excluding that of the Diluvium



epoch (Code 01).

Fig.••Vibration-damage correlation combining three earthquakes in Hokkaido

3.4 Vibration-damage correlation in Kagoshima:

The vibration-damage correlation based on geographic classification and obtained by combining data from the first and second Northwest Kagoshima Earthquakes was as high as 67% in undulating highlands (Code 01), and that of the surface rock classification (including the surface age) was 49% in the consolidated and semi-consolidated/consolidated sediment of the Palaeozoic and Mesozoic eras (Code 04).

PREDICTION OF EARTHQUAKE DAMAGE IN HOKKAIDO

In this study, the vibration-damage correlation of the three earthquakes in Hokkaido was analyzed based on geographic classification. As a result, the following facts were clarified: damage caused by the estimated acceleration frequently occurred in the alluvial fans and deltoid lowlands (Code 07), undulating highlands (Code 03) and undulating mountains (Code 01). Meanwhile, damage occurred less frequently in undulating volcanoes (Code 02) and rock plateaus (Code 06).

The correlation in the surface rock classification (including the surface age) was also examined. As a result, it was indicated that damage caused by the estimated acceleration frequently occurred in unconsolidated sediment (Codes 01 and 02), but less frequently in the semi-consolidated/consolidated sediment of the Paleozoic and Mesozoic eras and Jurassic and Cretaceous periods (Code 4), as well as pumice flow sediment and pyroclastic ejecta of volcanic rocks (Code 05).

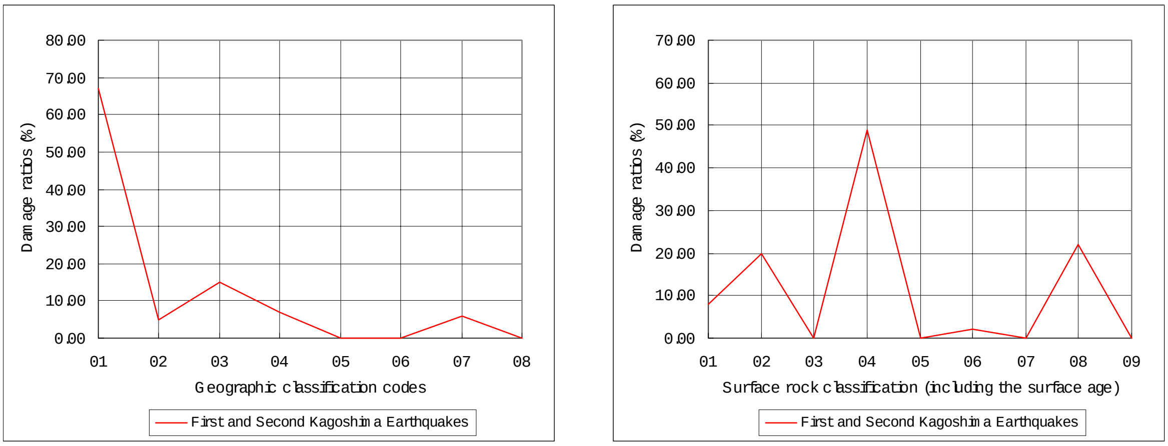


Fig.•Vibration-damage correlation combining the first and second northwest Kagoshima earthquakes

COMPARISON BETWEEN HOKKAIDO AND KAGOSHIMA

Earthquake damage for Hokkaido and Kagoshima was compared using the correlation in geographic classification caused by estimated acceleration. As a result, no correlation was observed in the damaged areas in Hokkaido and Kagoshima. Both in Hokkaido and Kagoshima, however, damage less frequently occurred in undulating volcanoes (Code 02) and rock plateaus (Code 06). Regarding the surface rock classification (including the surface age), no correlation was obtained regardless of the number of damaged areas.

CONCLUSION

This study estimated the acceleration of earthquake vibrations based on the data for three earthquakes in Hokkaido and their associated damage on road structures, and examined the correlations between earthquake vibrations and the geological characteristics of the damaged areas.

As a result, the vibration-damage correlation was elucidated and damage prediction was examined based on the characteristics of the ground in Hokkaido. Damage more frequently occurred in areas geographically classified as alluvial fan and deltoid lowlands and undulating highlands and mountains, and in the unconsolidated sediment in a surface rock classification (including the surface age). No correlation was observed between Hokkaido and Kagoshima, which was thought to be due to the unique regional characteristics of Hokkaido.

In the future, more data elements should be incorporated to achieve higher accuracy and obtain more refined results for damage prediction