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EARTHQUAKE AND WIND RESPONSE OF BASED-ISOLATED WOODEN HOUSES USING MR DAMPER

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SUMMARY

Developments of lock system for based-isolated wooden houses are conducted using Magneto-rheological Fluid damper (MR damper). In this system, damping force of MR damper can be changed by simple mechanism in which magnetic field by permanent magnets is controlled by falling moment of magnets. Dampers for cars which can be obtained easily are used taking the cost into account.

Dynamic vibration test of the MR damper is carried out to investigate mechanical properties and adaptability of previously proposed model. Load – displacement curves of MR damper can be represented by velocity powered model, and parameters of model are obtained from test results. Using this model, earthquake and wind response analysis is carried out for 2-story based-isolated wooden house. The lock system of MR damper is controlled that isolated layer is locked until 45m/s wind velocity and unlocked at 100gal or 200gal acceleration of earthquake motion. For earthquake motion, analyzed responses in case of MR damper show almost same tendency with ordinary viscosity damper. For wind, responses using locked MR damper decrease under half of viscosity damper.

INTRODUCTION

Recently, isolated wooden houses have been focused on in Japan. Ball bearings or slide bearings with oil dampers are utilized for many of developed isolated wooden houses. Natural period of isolated structures sets to larger by decreasing stiffness of isolated layer using low stiffness bearings. In addition, earthquake energy is absorbed by oil dampers, and responses are made small. However, stiffness of isolated layer must be set very small in order to increase natural period because weight is very small as for the wooden house. As a result, daily-life vibrations and response in strong wind become a problem. Therefore, lock system is necessary to act isolations in vibrations of earthquake. In addition, it becomes a problem in wooden houses that a cost to make isolation system is high.

On the other hand, Magneto-rheological Fluid (MRF) has attracted attention as materials which mechanical properties can change by adding magnetic field. MRF has been focused in the field of control

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and isolation system of building engineering. MRF is applied to energy absorption elements such as MR dampers.

In this paper, developments of lock system for based-isolated wooden houses are conducted using MR damper. In this system, damping force of MR damper can be changed by simple mechanism in which magnetic field by permanent magnets is controlled by falling moment of magnets themselves. Dampers for cars which can be obtained easily are used taking the cost into account.

LOCK SYSTEM USING MR DAMPER

Outline of the lock system using MR damper is shown in Fig. 1. A damper for a car is used to the main body of the damper. Damping force of MR damper is changed by magnetic field of permanent magnets attached to the lock system. In usual, MR damper is locked by magnetic field to have non-isolated state. Input energy of a strong wind is absorbed with small displacement by MR damper. In the case of earthquake, permanent magnets fall down at the target acceleration. MR damper behaves as same as ordinary oil damper. Sufficient isolation effect can be expected by enough energy absorption due to large displacement.

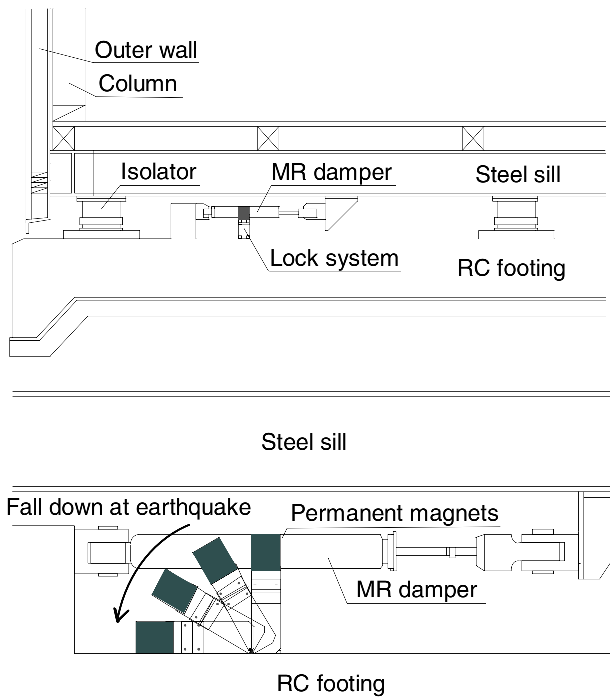

Fig. 1 Outline of MR damper lock system

DYNAMIC VIBRATION TEST OF MR DAMPER

Outline of Test

A damper for the car (2000cc class, 1360kg weight) is used for main body of MR damper with permanent magnet of magnet base. MRF made in Bando Chemical Industries (Bando#230) and the base oil is used for the cylinder inside. The damper was processed to have two injection holes in order to fill the MRF or base oil inside.

Using the vibration table shown in Fig. 2, the sine wave vibration test was carried out to investigate mechanical properties of MR damper. Tested cycle patterns are shown in Table 1. The measurement items were load and piston displacement of the damper. These were measured by a road cell for 30kN and inductance type displacement transducers. In case of loading with magnetic field, permanent magnets were put on the damper directly. Hereafter, identifications are defined that "MRon" indicates the case with magnetic field, "MRoff" indicates the case without magnets, and "OIL" represents the damper using only base oil. At least five cycles were loaded in vibration test.

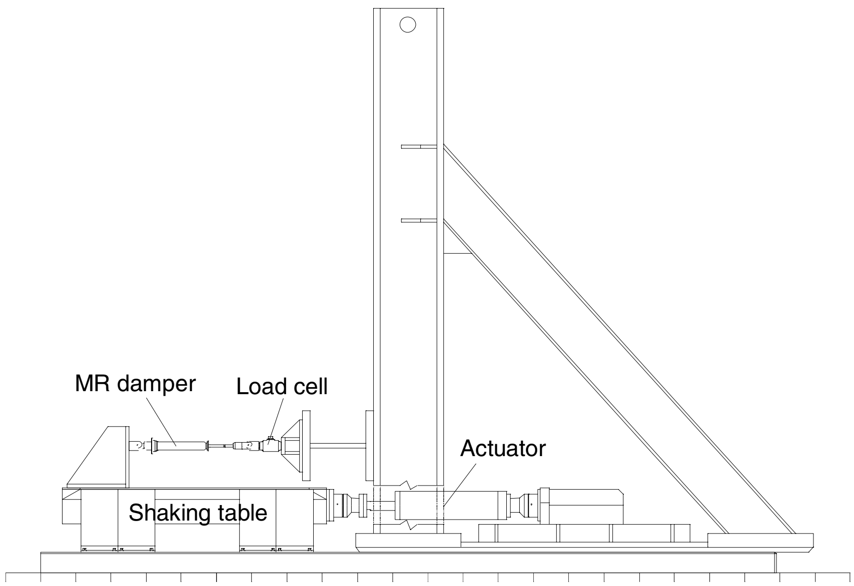

Fig. 2 Loading method

Table 1 Sine wave vibration patterns

Amplitude (mm)	Frequency (Hz)				
	0.1	0.2	0.5	1	2
5	-	O	O	O	O
10	-	O	O	O	-
15	O	O	O	-	-
20	-	O	O	-	-

Load – Displacement Curves

Because damper characteristics are different between pushing and pulling state, an averaged load – displacement curves are estimated. Typical load – displacement curves are shown in Fig. 3 in case of 0.2Hz sine wave with 20mm amplitude. A maximum load difference of MRon and MRoff is about 0.1kN. MRon curves surrounded MRoff curves, and loop characteristics are able to recognize differences.

Relationship between Maximum Load and Piston Speed

Relationships between maximum load and piston speed are shown in Fig. 4. Increment ratio of maximum load for speed is almost same between MRon and MRoff. Yielding load increases a little in case of MRon due to magnetic field of permanent magnet.

Modeling of MR Damper for Response Analysis

It is considered that velocity powered model, $F = CV^{\alpha}$, which has been proposed in the previous study [1] is suitable to represent load – displacement curves of MR damper in this test. This model has only two parameters, so estimation becomes easier. The tested curves are modeled using the velocity powered model. The parameters are damping coefficient C and powered number a.

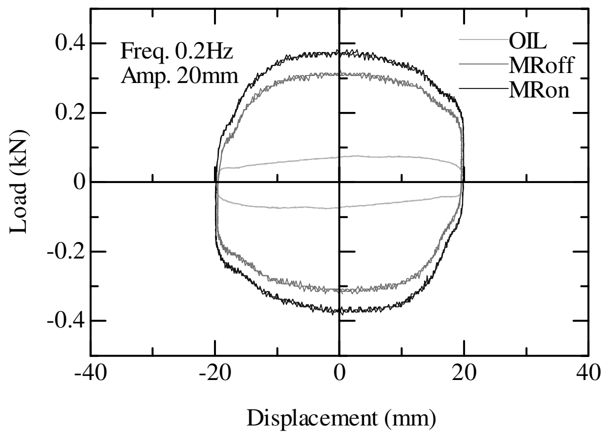

Fig. 3 Load - displacement curves (0.2Hz, 20mm)

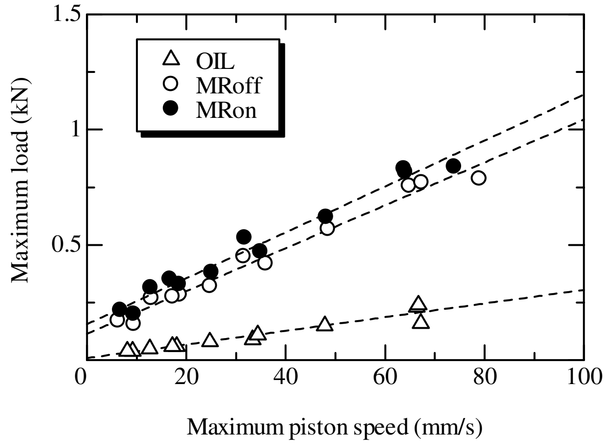

Fig. 4 Max. load – Max. speed relations

Table 2 represents estimated parameters by maximum load and piston speed relationships shown in Fig. 5. It is recognized that there are some differences of parameters between MRon and MRoff. The change of slope for the case of MRon is larger than the case of MRoff.

Table 2 Parameters for velocity powered model

Case	C (kN(s/mm)$^{-\alpha}$)	α
MRoff	0.042	0.672
MRon	0.059	0.618

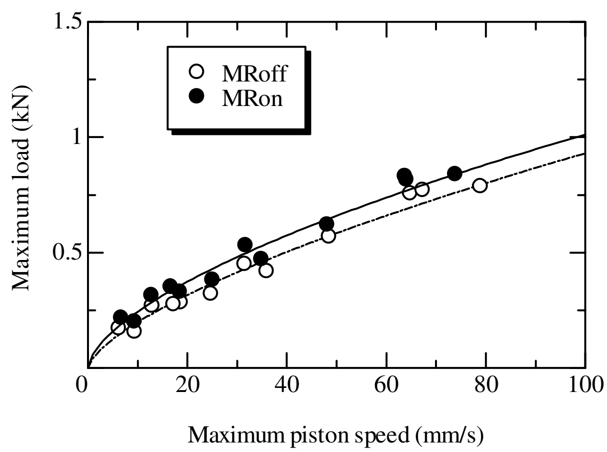

Fig. 5 Maximum load - maximum speed relationships

Comparison of load – displacement curves between test results and models are shown in Fig. 6 and Fig. 7 for the case of MRon and MRoff, respectively. Though modeled curves can not represent the slope of tested curves, the maximum loads of model well correspond to tested values.

It is concluded that modeling for MR damper using car's damper with permanent magnet is possible by velocity powered model as same as previously proposed MR damper.

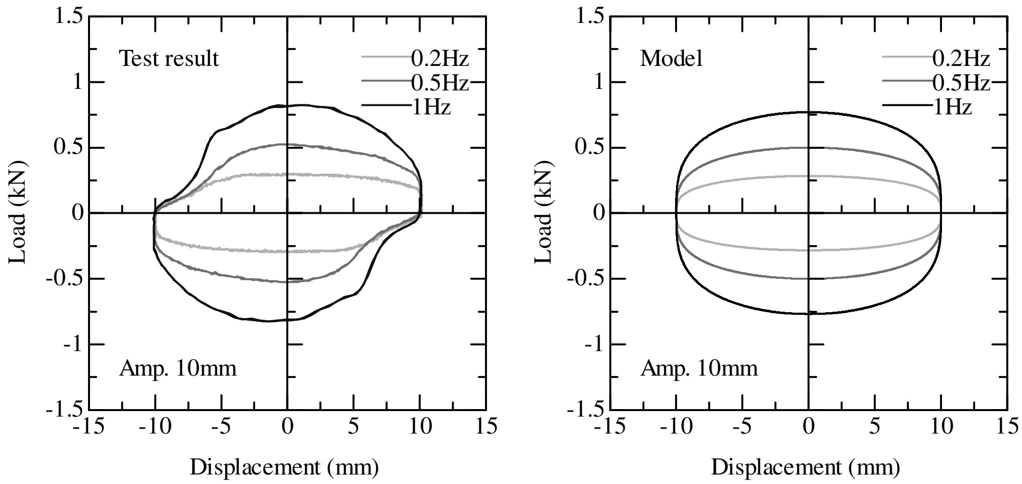

Fig. 6 Model curves for MRon

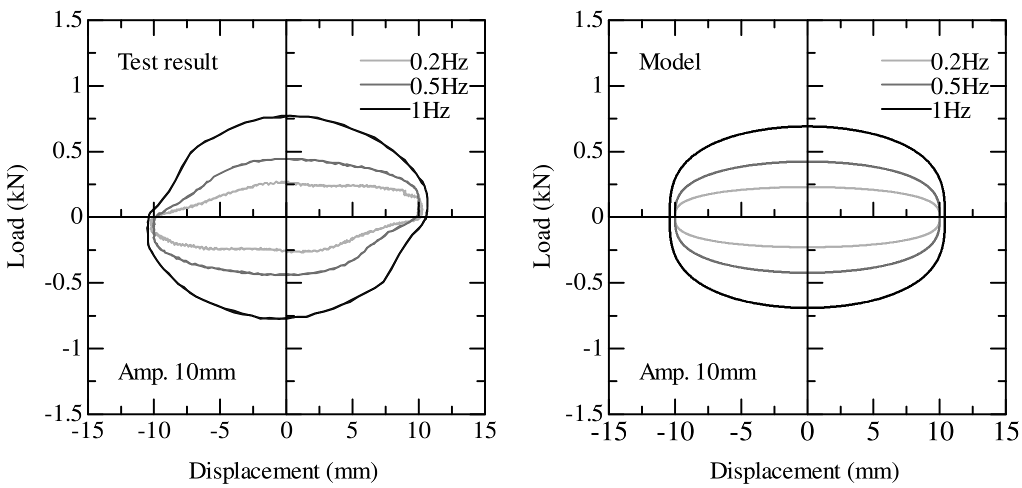

Fig. 7 Model curves for MRoff

RESPONSE ANALYSIS FOR EARTHQUAKE AND WIND

Preliminary Analysis

Influences of damping coefficient, *C*, of MR damper to the response of isolated wooden house by earthquake motion and wind force is investigated as preliminary analysis.

A 2-story isolated wooden house having the isolated layer is analyzed. The weight of the house is 35 tones. The analyzed house is modeled into single-mass with one degree of freedom. The isolators which are set on the isolated layer are supposed as slip type bearings with friction coefficient of 0.04. The load – displacement curve of the isolator is defined as bi-linear type restoring force. The stiffness of the first line is set to have 100 times of secondary stiffness due to friction force. The secondary stiffness is decided from natural period which is estimated as 3 seconds. The velocity powered model shown in Eq. (1) is used to represent MR damper.

$$F = C \cdot V^{\alpha} \tag{1}$$

Where,

F : Damping force of damper

V	: Piston speed:
C	: Damping coefficient due to magnetic field
α	: Multiplier due to magnetic field

The parameters for MR damper model are set to 0.2 as the multiplier, α, and five values (0, 20, 40, 60, 80) as the damping coefficient, C, for the case of MRon. For the case of MRoff, these values are 0.6 as α and 0, 1, 3, 5, 10 as C. Analysis is carried out by direct integration using linear acceleration method.

The two simulated waves modified by Building Center of Japan (BCJ-L1 and BCJ-L2), El Centro, Kobe (JMA) and Hachinohe waves which are modified to have 50kine velocity are input as earthquake motions. The wind forces are made by superposition of trigonometric functions to specify power spectrum density based on the Standard of Design Force of Buildings established by Architectural Institute of Japan. Four wind forces are prepared to have recurrence intervals of 1, 10, 50 and 100 years for specified height of 6m and width of 10m. In the case of analysis for earthquake response, magnetic field of MR damper is not affected. In the case of analysis for wind response, it is acted to MR damper.

Fig. 8 shows relationships between damping coefficient and analyzed maximum response. The similar tendency both for earthquake and wind response is observed. Sufficient isolation effect can not be expected when the damping coefficient becomes too large.

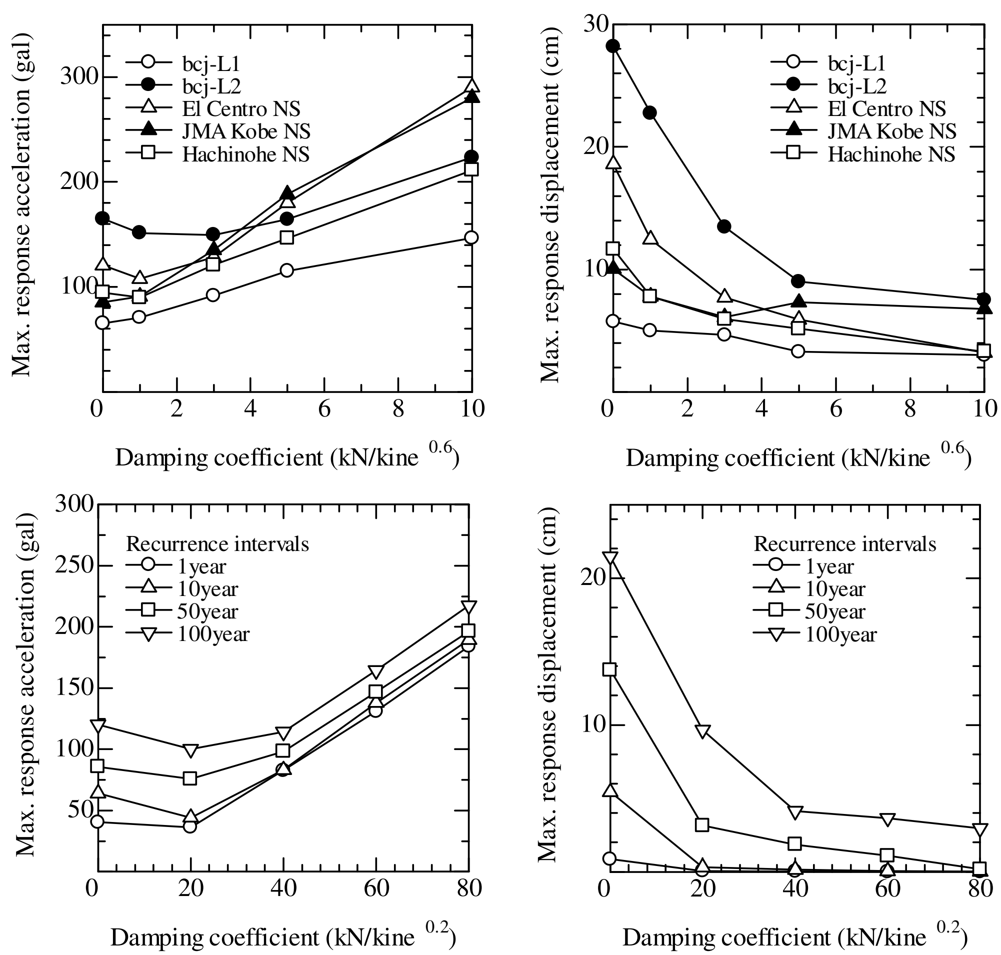

Fig. 8 Analyzed maximum response in preliminary analysis

Proposal of Appropriate Characteristics for MR Damper

Proposal of appropriate characteristics of MR damper is conducted through earthquake and wind response analysis to show enough isolation effect in spite of any friction coefficient of isolators.

The target isolated house is 2-story wooden house with MR lock system. To compare the isolation effect, ordinary wooden house without isolator is also analyzed. Restoring force of w/o isolator house is set as superposition of bi-linear and slip type with the ratio of 3:7. Damping factor of 10% is defined.

Isolators for isolated house are modeled by bi-linear type as same as the preliminary analysis. Friction coefficients are set to 0.01, 0.05 and 0.1. Secondary stiffness is calculated to have natural period of 3 seconds, and primary stiffness is set to 100 times of secondary stiffness.

Three types of damping systems are analyzed. One case is only isolator without damper, the other case is isolation with viscosity oil damper with velocity proportional type, and the other case have MR damper with lock system. Each parameter is shown in Table 3, these are based on the preliminary analysis. Two types of lock system are considered. (A) MR damper is locked until 45m/s wind velocity and unlocked at 100gal acceleration of earthquake motion. (B) MR damper is locked until 45m/s wind velocity and unlocked at 200gal acceleration of earthquake motion.

Table 3 Parameters list

Friction coefficient for isolator	Damping coefficient of MR damper		Damping coefficient of oil damper (kN/kine)
	MRoff ($kN/kine^{0.6}$)	MRon ($kN/kine^{0.2}$)	
0.01	4	40	1.47
0.05	3	30	0.98
0.1	2	20	0.49

Analysis is carried out by direct integration using Newmark β method. The two simulated waves modified by Building Center of Japan (BCJ-L1 and BCJ-L2), El Centro, Kobe (JMA) and Hachinohe waves which are modified to have 50kine velocity are input as earthquake motions.

The wind forces are made by superposition of trigonometric functions using random number to specify power spectrum density based on the Standard of Design Force of Buildings established by Architectural Institute of Japan. Five wind forces are prepared to have average wind speeds of 15, 20, 25, 30 and 35 m/s for specified height of 6m and width of 10m.

Maximum responses of each analysis by El Centro are shown in Fig. 9 as typical examples. Fig. 10 and Fig. 11 present relationship between wind speed and maximum responses.

Response displacements in case of MR damper lock system are almost same as those in case of viscosity oil damper. Response accelerations decrease rather than viscosity oil damper. Considering wind responses, response accelerations show a slight increment in case of friction coefficient of 0.1. However, response displacements are controlled under half of viscosity damper.

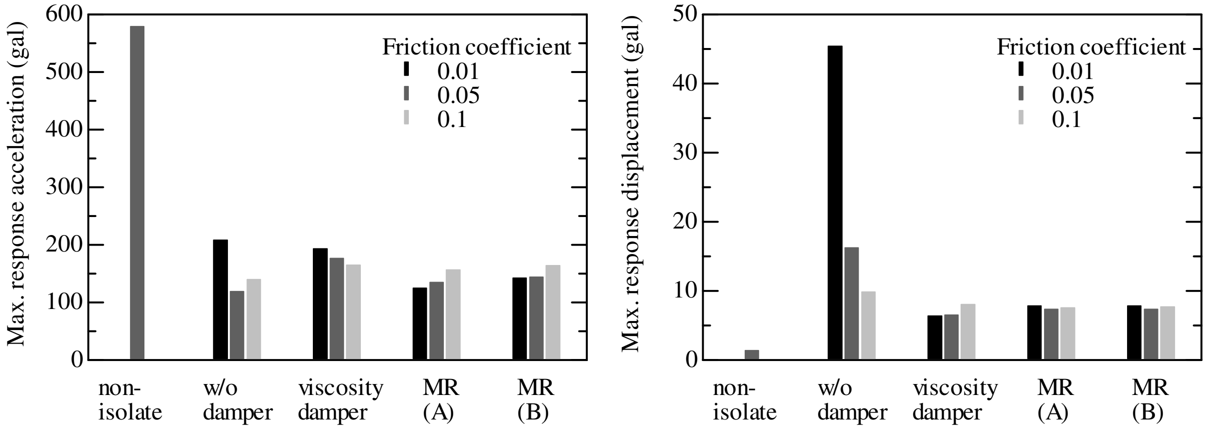

Fig. 9 Response of each model by El Centro

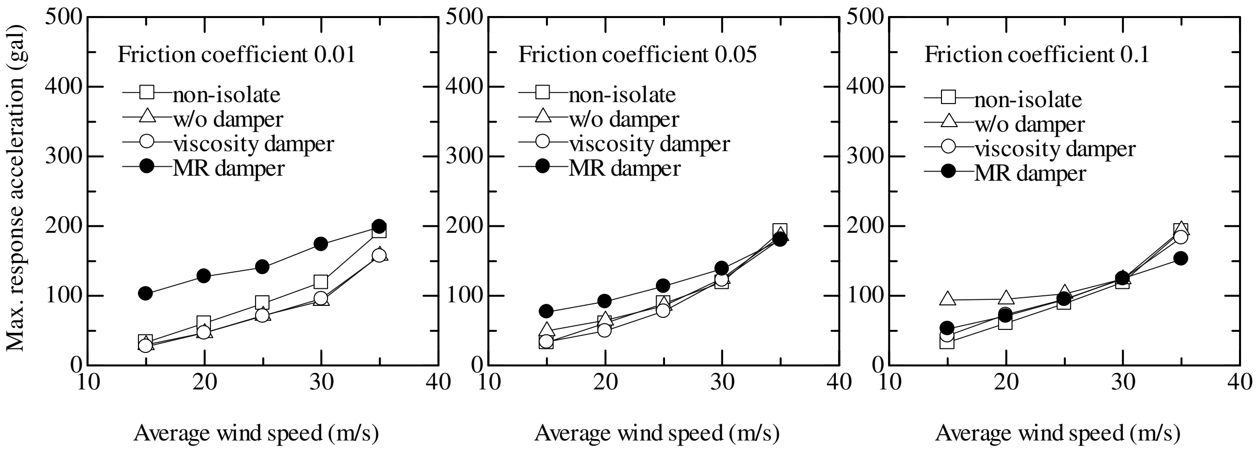

Fig. 10 Wind speed and maximum response acceleration

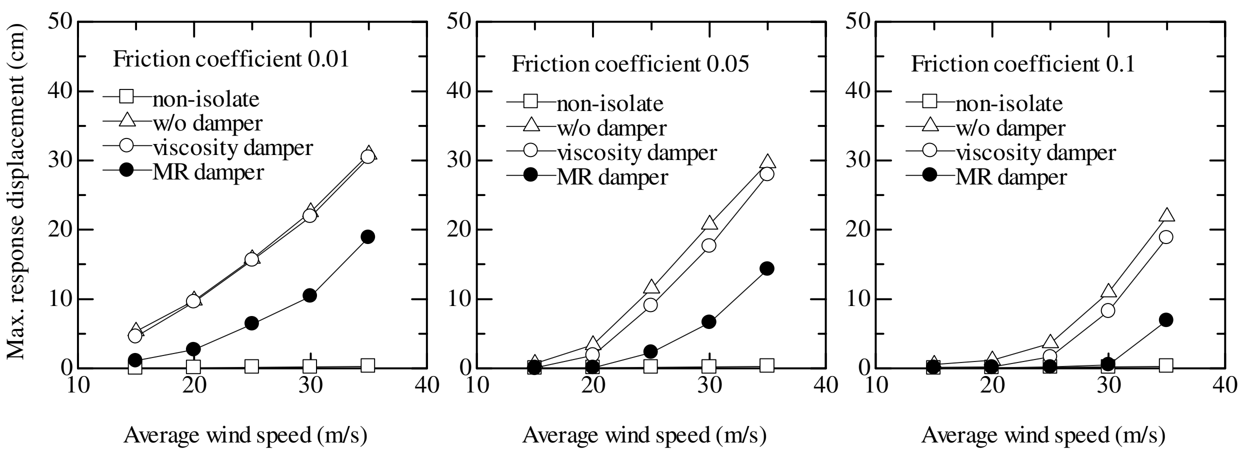

Fig. 11 Wind speed and maximum response displacement

CONSLUSIONS

Dynamic vibration test of the MR damper using damper for a car was carried out to investigate mechanical properties and adaptability of previously proposed model. Load – displacement curves of MR damper can be represented by velocity powered model, and parameters of model were obtained from test results. Using this model, earthquake and wind response analysis was carried out for 2-story isolated wooden house. The lock system of MR damper is controlled that isolated layer is locked until 45m/s wind velocity and unlocked at 100gal or 200gal acceleration of earthquake motion. For earthquake motion, analyzed responses in case of MR damper show almost same tendency with ordinary viscosity damper. For wind, responses using locked MR damper decrease under half of viscosity damper.

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