PRELININARY RESEARCH ON THE MATERIAL FOR THE DAMPER WITH ROTATING RINGS

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ABSTRACT: A concept of new low cost damper with long stroke, damper with rotating rings, is introduced. Some process of seeking appropriate material for the ring of the damper is reported.

Key Words: *Damper, Base-isolation, O-ring, Stainless rope, tin*

1. INTRODUCTION

Dampers are now frequently applied to building structures to ease their dynamic response. Various types of dampers, utilizing rheological, viscos-elastic or plastic property of material, are developed and applied. Buckling restrained braces are sometimes regarded as sorts of dampers. When dampers are applied as energy dissipating devices to reduce the overall dynamic response of the structure they are arranged vertically distributed manners.

When the dampers are employed in a seismic isolation system they are usually horizontally distributed in a particular isolation layer of the buildings. In such an application for seismic-isolation system, the dampers are usually required to have long strokes in order to accommodate with the large dislocation between two separated parts, foundation and superstructure of the building. For large buildings hydraulic jacks are conveniently used. However for seismic-isolation for smaller residential houses hydraulic jacks are too expensive and high-speck. There are demands for low cost dampers with long strokes.

The authors have proposed a simple system for dampers with longer stroke by using rotational deformation of rings (torus) (Fig.1). Thanks to its simple constitution it can be produced at low price. By changing the number of rings the resistance-force of the damper can be easily adjusted.

In this article the results of the research of the material for the rings of this type of damper are reported.

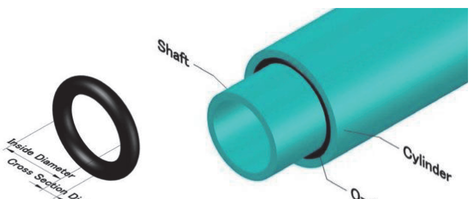

Fig.1 The Composition of the Ring Damper

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1.1 The Damper System

The schematic view of the basic constitution of the damper is indicated in the Fig.1. A steel pipe with smaller diameter, the shaft, is inserted into another steel pipe with larger diameter, the cylinder. A set of rings are set around the shaft with regular intervals and inserted in the cylinder. The rings are squeezed between two pipes. When the two pipes relatively move in a telescopic manner each of the squeezed rings is forced to roll around its circumferential axis. No matter what kind of material used for the ring, the material moves to the outer edge of the ring is subjected to tension strain and the inner edge compression. As the ring rolls the material is subjected to successive tension and compression alternately. This continuous transformation of the motion, axial telescopic motion to the rotation of rings, can be used for the consumption of the dynamic energy.

1.2 The feature of the ring damper

After the 360-degrees-rotation the ring moves along the axis of the shaft but the material comes back to the initial position. Since this movement can be repeated endlessly or inversely the long stroke of the damper becomes possible.

The resisting force of the damper can be easily varied by adjusting the number of rings.

2. Dynamic loading test

2.1 Purpose

For the first step of the development of the damper, the rubber O-rings, which are commercially available, were selected as the low-cost energy dissipating material and the damper set was assembled with them. O-rings with several different kinds of rubbers were researched. In this section the results of polyurethane rubber are reported. In order to grasp the dynamic performance of the damper we carried out a series of dynamic loading tests.

2.2 Outline

The geometric detail and material used for the damper are indicated in table1. Thirteen O-rings made of polyurethane rubbers are aligned along the shaft of the damper. Nine types of specimens are prepared and tested. For the first three specimens, V-1, 2 and 3, the loading velocity was changed in a various range. The two specimens in the second group were tested starting with different temperature. Finally the four specimens in the third group were subjected to a hundred or fifty times of cyclic strokes (Table2). The set-up of the experiments is indicated in the fig.2. The amplitude of the sinusoidal repeating stroke was ±50[mm].

Table1: Configuration of the Specimen

Item	Material	Number	Inside diameter	Wire diameter	Length[mm]
O-ring	Urethane	13	φ20	φ5	-
Cylinder	SS400	-	-	-	400
Shaft	SKTM13A	-	-	-	400

Table2: List of Specimens

Test item	Test name	Velocity[kine]	Temperature[℃]	Repeated time[times]
Velocity dependence test	V-1	10,30,50,80	24	10
	V-2	〃	〃	〃
	V-3	〃	〃	〃
Temperature dependence test	T-1	30	-10,10,24,40,60	10
	T-2	〃	〃	〃
Repeat dependence test	N-1	30	24	100
	N-2	〃	〃	50
	N-3	〃	〃	〃
	N-4	〃	〃	〃

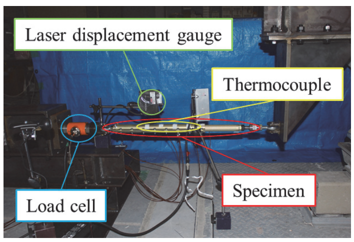


Fig.2 The installation situation of the specimen

2.3 Results

Some of the results of the experiments of O-rings are shown here. The load - displacement curves are indicated in fig. 3. The dependence of the damping force to the loading speed, initial temperature of the material or the number of repetition, is indicated in figs. 4, 5 and 6. Just like static loading test, the load-displacement relationships of the ring damper showed a hysteresis curve of plastic material. As loading speed became faster or specimen's temperature became hotter, the resistance force of the damper became lower.

The damping effect of the O-rings may be due to the visco-elasticity property of rubber material. When the temperature of the O-ring got higher the damping force became lower.

Sudden and fatal collapse of the rubber material of the O-rings was observed in several tests. (see fig.7) Results of such cases of the test are reported in table 3. The surface temperature of the cylinder exceeded 50 [℃] in the most of the cases but V-3. It is possible that when the cylinder surface reached 50[℃] the temperature of the rubber material, urethane, reached about 70[℃], which is limit temperature for the urethane rubber.

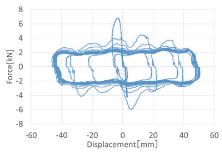


Fig.3 Load-displacement relation (V-1_10kine)

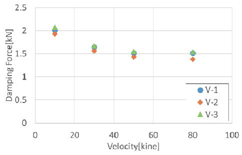


Fig.4 Loading speed dependence

Table3: O-ring damaged test outcome list

Test	Velocity[kine]	Temperature[℃]	Repeated time[times]	Damping-force[kN]	Surface temperature[℃]	
					before	after
V-3	80	24	10	1.54	23.4	33.3
T-1	30	60	10	1.16	-	-
N-1	30	24	100	0.83	24.1	63.9
N-2	30	24	50	1.05	22.9	51.3
N-3	10	24	50	1.26	25	50.1
N-4	10	24	50	1.79	24.1	53.5

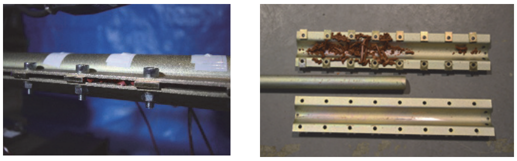


Fig.7 O-ring damaged circumstances

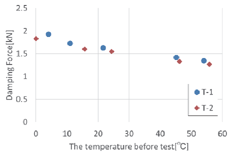


Fig.5 Temperature displacement

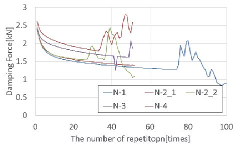


Fig.6 Repeat displacement

3. Other Material

3.1 The required performance of the ring

After observing sudden collapse of the rubber material investigation for new material of the rings. Required performance for material of the O-ring damper may be summarized as follows.

1. High energy dissipating performance
2. High damping force
3. Heat-resistance
4. Good quality for long stroke
5. Low cost

In order to fill such requirement the following material was utilized and tested in different ways. Among them, stainless ropes and tin rings are reported here.

1. High damping rubber
2. Heat-resistant urethane
3. Stainless rope
4. Fastening tape (so-called velcro)
5. Tin

Table4: The physical property of stainless wire

Composition	Material	Wire diameter [mm]	Elastic coefficient [N/mm2]
7×7	SUS304	φ5	105930
7×19			97110

(a) 7×7 (b) 7×19

Fig.8 Wire composition

Fig.9 Wire ring

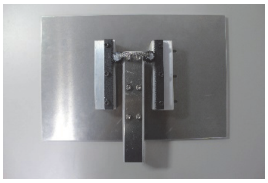


Fig.10 Rack & pinion system

3.2 Stainless rope

Expecting energy dissipating effect by friction among wires rings made of stainless rope were tested. (Fig. 9) The outline of the two types of ropes used for rings is indicated in table4 and fig.8. The limit temperature is beyond 500 [℃]. Unlike O-rings, the "rack and pinion" system was employed to set up rotational movement for the wire rings.

3.3 Tin

The physical properties of the tin are indicated in table 5. Tin is soft metal and has excellent plastic deformation property. Plastic deformation by rotational movement of tin rings is expected for energy dissipating component of the damper. The recrystallization temperature of tin is in the range of the room temperature. Therefore plastic deformation doesn't stay or accumulate permanently.

Tin ring cannot roll around the shaft by its own friction. In order to provide enough friction between tin ring and the shaft a rubber tube was fit on a tin line (fig. 11). The solvent welding was used to make a tin ring, after putting the rubber tube on. (fig. 12)

Table5: The physical property of tin

Stiffness [GPa]	Elastic limit strain [10^-4]	Melting Point [℃]	Thermal conductivity [W/m/℃]	Specific heat [J/℃・kg]	Recrystallization temperature [℃]
51.9	3.7	231.9	64.9	226	0∼25℃

Fig.11 Tin-ring

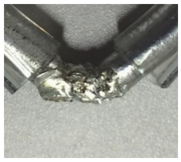


Fig.12 Welded part

4. Results

4.1 Outline of Simple Test

In order to grasp basic performance of rings made of stainless rope and tin the simple tests were carried out.

4.2 Stainless rope

Stainless rope ring with a pair of pinion gears is freely loaded by weight under gravity load in the fixed rack system, shown in fig.13. The parameters for specimens are indicated in table 6 and a test item is indicated in table 7.

The load-rotation angle relations of R-2 and E-1 are indicated in figs. 14 and 15, respectively. A wire ring recorded the damping force different from maiden loading besides that. The rope ring showed a certain resistance against vertical load. However the level was about 12[kgf], quite low.

Table6: Specimen outline

Specimen name	Composition	Circumferential length[cm]
SWR1	7×19	16.5
SWR2	7×7	20
SWR3	7×19	16

Table7: Test item

Test	Purpose	Specimen
R-1	To grasp resitance-force	SWR1
R-2	〃	SWR2
E-1	To confirm energy dissipating perfprmance	SWR2
E-2	〃	SWR3

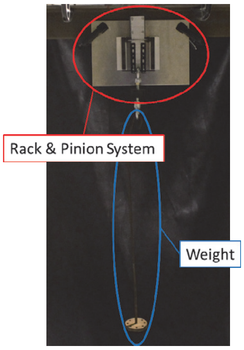


Fig.13 Test equipment

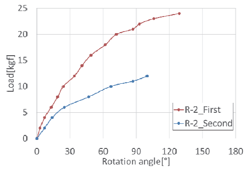


Fig.14 R-2
Load-Rotation angle

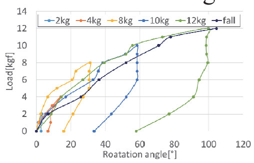


Fig.15 E-1
Load-Rotation angle

4.3 Tin ring performance test

Figs. 16 show the set-up for the tin ring test. The cylinder used in this test is the same one as was used for the dynamic loading test described in 2.3 and 2.4. A screw stock was used as the shaft. Preliminary studies were performed (table 8) and φ 4_M24 screw stock was selected.
Crudeness of solvent welding was considered and four rings were prepared (fig. 17).

Test results are listed in table 9 and the load-displaced relationships are indicated in fig.19. Shapes of the ring before and after the test are indicated in fig. 19. The resistant forces of all specimens are measured as more than 900[N]. There was a specimen, Ring 2, in which joint fracture observed.

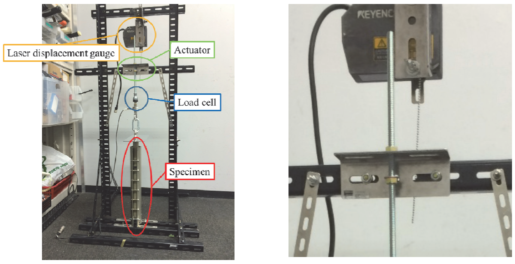
The load-displacement curves exhibited the elasto-plastic features. Resisting force gradually decreased after the first maximum point. However even in the degrading phase the resistance force was rather stable, about 400 [N]. The oscillating shapes of the load-displacement curves are due to the shape of the shaft, a screw stock.
After the test clear distortion was observed in the shape of the tin rings. One of the reasons of this distortion is the use of screw stock for the shaft. There may be a possibility to remove such a distortion by using other material having more even surface.
A tin ring is satisfied to some extent with the required performance of the ring mentioned in the section 3.1

Table8: Result list of prelims

Specimen	Diameter of tin line	Tube size[mm] (inside × outside)	Diameter of shaft	Presence of rolling around
φ4_M22	φ4	4×6	M22	Slip
φ4_M24			M24	Rolling around
φ5_M22	φ5	5×8	M22	Don't move

Table9: Results of the tests

Specimen	Load of start to roll around [N]	The smallest load[N]	Displacement[cm]		Note
			Ring	Shaft	
Ring 1	951.32	472.7	3.5	7	Joint fracture
Ring 2	905.01	399.93	-	8	Joint fracture, Ring deformation
Ring 3	937.21	380.68	-	5.5	Ring deformation
Ring 4	966.74	513.18	3.5	6.5	



(a) General View (b) Detail

Fig.16 Test set-up

4.4 Resisting force of the ring

Resisting force of the ring can be roughly estimated by a simple calculation based on the relation between consumed plastic strain energy and work done by the applied load.

When the perfect plasticity is assumed for the stress-strain relationship of tin, the resisting force F is expressed as in the following equation,

$$F = \frac{4\pi R\sigma_y}{r}\{R^2 \sin^{-1}(\frac{r}{R}) - r\sqrt{R^2 - r^2}\} \qquad (1)$$

σ_y:Yield stress

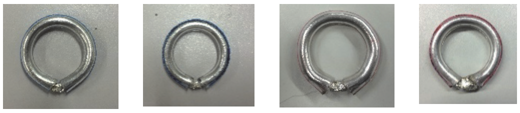
where R is the radius of the ring and r is the section radius of the tin line.

For the parameters used for the test (R=15[mm], r=2[mm], σ_y=19.203[N/mm^2]), the equation (1) gives F=647 [N], which is roughly close to the test results.

Influence of the parameters was considered using the equation (1). As the result, if the section radius r of the ring (the wire diameter) becomes big, the resisting force rises like the index function (Fig. 21).

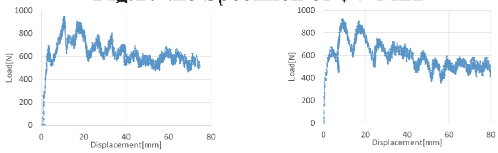
5. Conclusions

A concept for the new, low cost with long stroke damper, a damper with rotating rings, was introduced. For this damper there is a necessity to seek an appropriate energy dissipating material. Some of the test results, obtained in the course of searching material for the damper with rotating ring, were shown and discussed. A summary of the study is indicated in table 10. So far, tin seems the most suitable material for the use. However there are still some problems to be solved. How to produce the rings with specified parameters and how to get the enough friction to make the ring rotate are the problems need further studies.

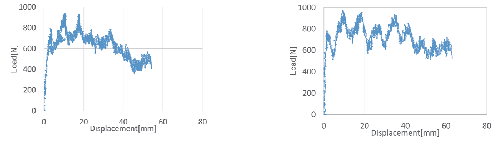


Ring_1 Ring_2 Ring_3 Ring_4

Fig.17 the Specimen of φ4 M22

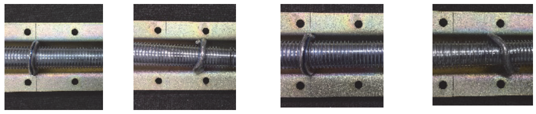


(a) Ring_1 (b) Ring_2

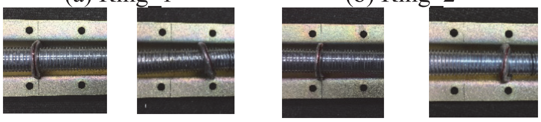


(c) Ring_3 (d) Ring_4

Fig.18 Load-Displacement relation

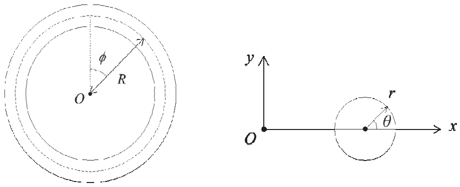


(a) Ring_1 (b) Ring_2



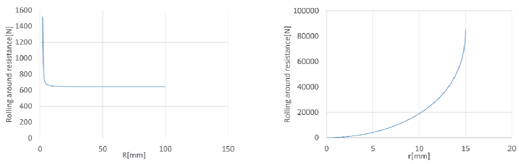
(c) Ring_3 (d) Ring_4

Fig.19 Shape of the rings (left : before, right : after)



(a) General view (b) The tin line section and coordinate axis

Fig.20 Ring specification



(a) r is fixed (*R* is parameter) (b) R is fixed (*r* is parameter)

Fig.21 Influence by parameter change

Table10: Summary of the Research

	Energy dissipating	Damping force (from experiment)	Heat resistance temperature[℃]	Securement of a stroke	Cost	
					Material	Making (for a ring)
High damping rubber	Hystettesis loss	-	60	Rolling around	¥2,700[/ring]	¥2,700
Heat resistance urethane	〃	-	120	〃	¥2,800[/ring]	¥2,800
Stainress wire	Friction	About 10[kg]	700～800	〃	About ¥250[/m]	About ¥1,700
Magic tape	Destruction & Friction	About 5[kg]	Having temperature dependency	Rolling	About ¥1,700[/m]	About ¥500
Tin	Plastic deformation	About 90[kg]	231.9 (melting point)	Rollimg around	About ¥4,000[/kg]	About ¥70