13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1851

RESERCH ON TENSILE TOGGLE DAMPER SYSTEM – SOME APPLICATIONS TO TRADITONAL TIMBER STRUCTURES

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SUMMARY

This paper describes the performance of passive damper devices adopting toggle mechanism, and some applications to actual buildings. Two kinds of developed damping devices are presented, which have adopted oil dampers as energy absorption equipment. The devices installed the coil shaped springs in parallel with the oil damper. Those springs are given tension beforehand so that the device can move only for tensional situations. The dynamic loading tests of the devices were carried out. The results of the tests showed the devices have stable and efficient energy absorption performance. Moreover, it was found through response analyses that the structures applied the devices have highly performance for major earthquakes.

INTRODUCTION

Major parts of structures built by the traditional method in Japanese have rather higher damping performances than those of buildings of reinforced concrete construction or steel construction. And also it is found clearly by the past studies that the deformation performance of the structures is excellent. However, it is clear that the preservation technique for historical buildings must be developed, by reason of the facts that there are not few examples which were collapsed by big earthquakes in even the last years. In such situations, two kinds of passive control device which combined the toggle mechanism and the oil damper were developed, and this paper describes the results of the full scale dynamic loading tests for those devices. Moreover, some applications to the traditional timber structures are reported.

OUTLINE OF THE DAMPER SYSTEMS

This section describes the outline of two kinds of developed damping devices. The outline of mechanism of the devices are shown in Figs. 1 and 2.

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Outline of “Tensile Toggle Damper System”

The one of new developed device is making use of the toggle mechanism shown in Fig. 1. In Fig. 1, the toggle mechanism is constituted when the points, B,C, and D, are connected by rods. In this toggle, when point A moves to A’, point B moves to B’. In this movement, the displacement of A’B’-AB is larger than the lateral displacement of ‘x’. Therefore, an energy absorption device are connected to the both points A, B, more efficiently damping system may be composed than the simple use of a damper. Now, the amplification of the lateral displacement is defined as β as shown in Fig. 1. In the new developed device, the points A, B are connected by an oil damper and the coil shaped spring in parallel. When the spring is stretched by tensional force introduced into rod-BC and rod-BD, this device can move only for tensional situations. From this situation, this device is called as "Tensile Toggle Damper System".

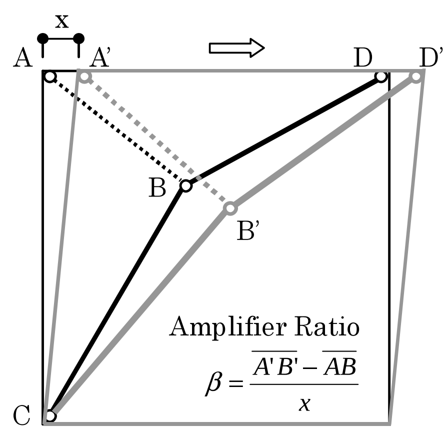


Fig. 1 Movement of Tensile Toggle Damper System

Outline of “Umbrella Shaped Damper System”

The mechanism shown in Fig. 2 is the acute-angle toggle mechanism composed by rod-AB and rod-BC. The new device is composed of combining two pieces of this toggle face to face. In Fig.2 the perpendicular displacement of ‘x’ transmits to the horizontal amplified displacement of ‘d’. Now the amplification of the displacement is defined as γ. If the oil damper and the coil shaped spring are installed between B and D, the efficient damper device may be composed. Moreover, by stretching the spring beforehand, the device can be move under its tensional behavior. In this paper, this device is called as "Umbrella Shaped Damper System".

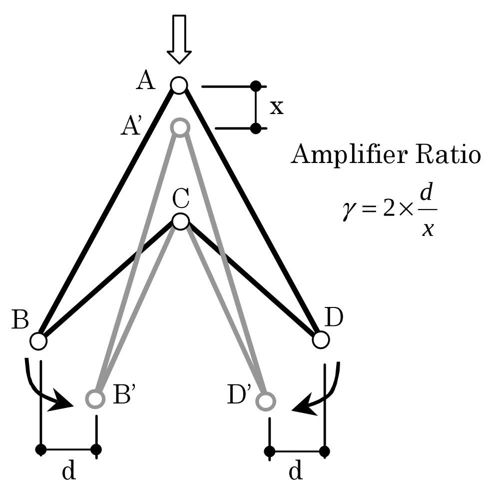
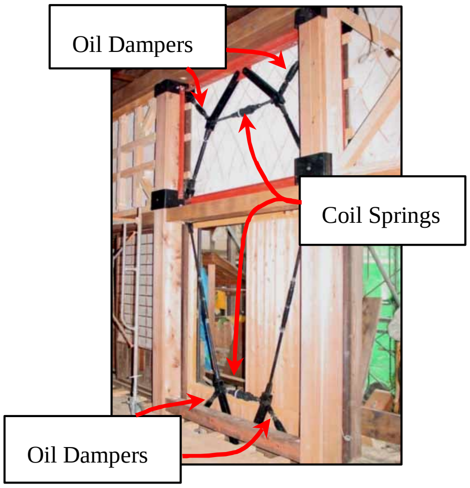


Fig. 2 Movement of Umbrella Shaped Damper System

After the good performance of those devices were verified by loading tests, those devices are applied to retrofitting of traditional Japanese timber structures as passive control. Fig. 3 is a photograph of the tensile toggle damper system installed in the wall of a timber structure, and Fig. 4 is a photograph of the umbrella shaped damper system installed in the other structure. The umbrella dampers showed in Fig. 4 is connected with the structure using steel rods, which arranges two sets of dampers in series to a diagonal.



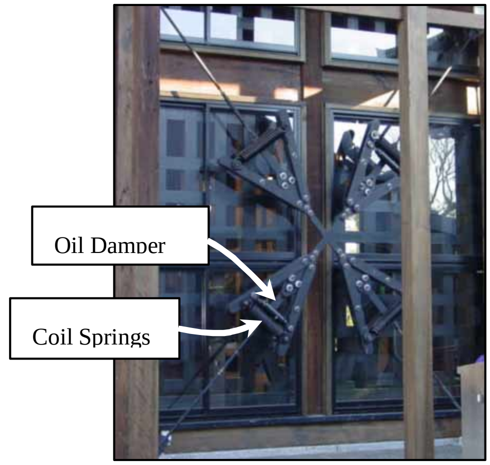


Fig. 3 Tensile toggle damper system installed in Japanese traditional timber structure

Fig. 4 Umbrella Shaped Damper System installed in Japanese traditional timber structure

DYNAMIC LOADING TESTS OF THE TENSILE TOGGLE DAMPER SYSTEM

This section describes the results of dynamic loading tests for the tensile toggle damper system. The outline of full scale experimental model is shown in Fig. 5. The experimental model is constituted by timber frame with installing the tensile toggle damper systems. The cross-sectional dimension of the column and the beam are 235mm square (wood material; Oregon pine), and the column and the beam are joined by tenons. The components which constitutes toggle mechanism are high tension bolts (ϕ 20 mm) and steel rods (ϕ 27 mm) which can adjust length by screws.

The method of producing the tension is shown in the right side of Fig. 5. The upper toggle system is tensioned by compressing the coil shaped springs (axial stiffness; 980 N/mm) which connected the toggle components on either sides. The lower toggle system is tensioned stretching the coil shaped spring (axial stiffness; 98 N/mm) installed in parallel with oil damper. By shortening the spring in the upper system by 10 mm and by stretching the springs in the lower system by 50 mm, the tensional load of the arms amount to about 30 kN. The toggle arms and the timber frame are connected with penetration bolts (ϕ 20 mm) through steel plates.

Oil dampers are installed in four corners of the frame as damping device. The characteristic of the oil damper is shown in Figs. 6 and 7. Fig. 6 is the relations between damping force and velocity. Fig. 7 is the relations between damping force and displacement in the frequency of 1.0 Hz. Design value of amplification ‘β’ of toggle mechanism is set up about 1.4 times in the upper toggle system and about 1.5 times in the lower toggle system.

The loading tests ware carried out by the actuater attached the steel beam (H-250$\times$250$\times$9$\times$14) at the top of the timber frame. Moreover, in order to present the roof weight of actual structure, the columns are compressed by perpendicular load of about 20 kN with jacks.

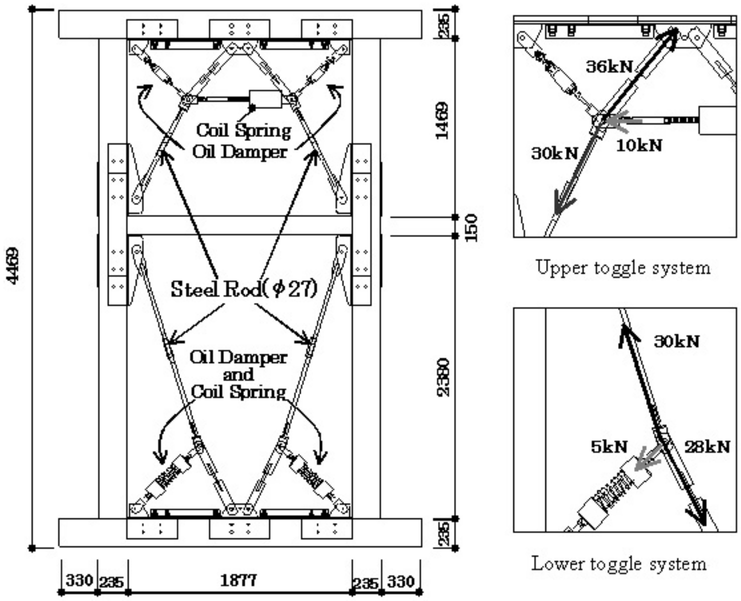


Fig. 5 Experimental model and tensional mechanism

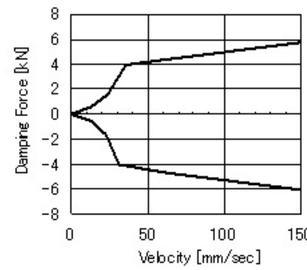


Fig. 6 Relations between damping force and velocity of oil damper

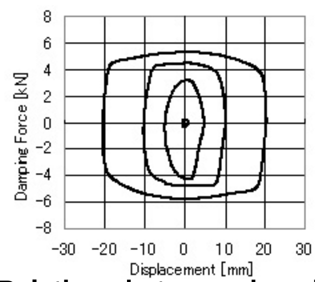
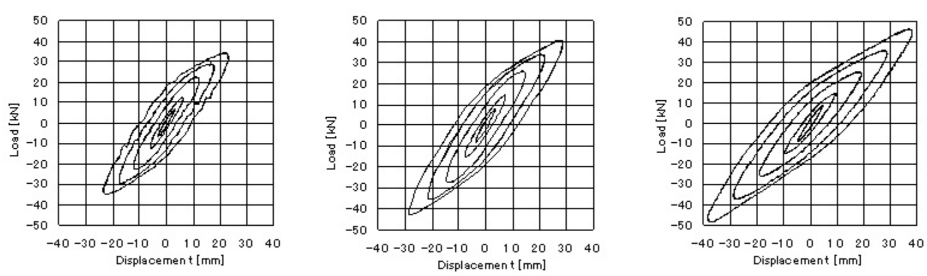


Fig. 7 Relations between damping force and displacement of oil damper

The relations between lateral load and displacement of top of the frame is shown in Fig. 8, which observed by the dynamic loading tests for loading periods of 0.7 seconds, 1.0 seconds, and 3.0 seconds. In those figures, it was shown that behavior's of the hysteresis loop are stable in any loading periods. The values of equivalent stiffness and equivalent viscous damping factors are computed from those results, and which are plotted for the loading periods shown in Figs. 9 and 10. In Fig. 9, the dependence for the equivalent stiffness around the periods of 1.0 second is found a little. In Fig. 10, the equivalent damping factors go on increasing, when loading periods become short. Moreover, the equivalent damping factors in the Fig. 10 have higher performances of 0.15-0.23 on an average.



(a) 0.7 sec (b) 1.0 sec (c) 3.0 sec

Fig. 8 Hysteresis loop by harmonic loading tests

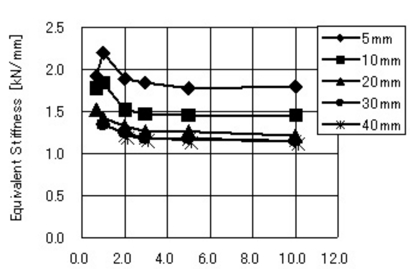


Fig. 9 Relations between equivalent stiffness and loading period

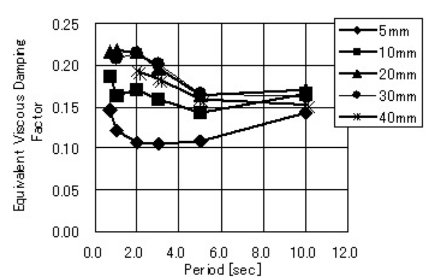


Fig. 10 Relations between equivalent damping factor and loading period

DYNAMIC LOADING TESTS OF THE UMBRELLA SHAPED DAMPER SYSTEM

This section describes the result of the dynamic loading tests for the umbrella shaped damper system. The outline of the full scale experimental model is shown in Fig. 11. The timber frame which installed the umbrella shaped damper system is the same as the frame described in the foregoing paragraph.

The form of the umbrella shaped damper used in this test is shown in Fig. 12. The device have the oil damper as energy absorption device(refer to Figs. 6 and 7, the characteristic of damping force), and have two coil shaped springs (axial spring stiffness of 45.0 N/mm) in parallel with the oil damper. The mechanism is constituted so that the device can move only for tensional situations, by giving the tensional stress to the springs beforehand.

Four sets of the umbrella shaped damper is installed in the experimental timber frame. In Fig. 11, the sets of TLD1 and TRD2, TRD1 and TLD2 are connected in series. The devices have connected to the timber frame by steel rods with the screw, which is tensioned by screwing up. In this tests, the design tensional stress amount to about 60 kN.

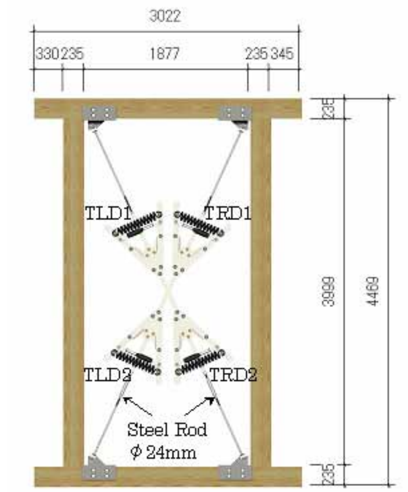


Fig. 11 Experimental model (unit:mm)

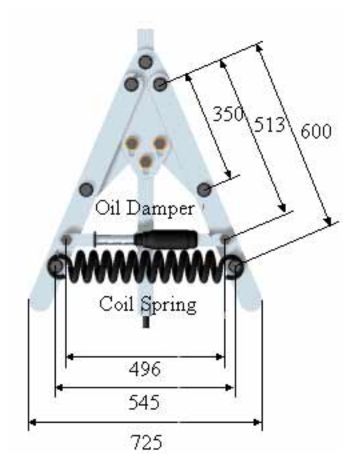
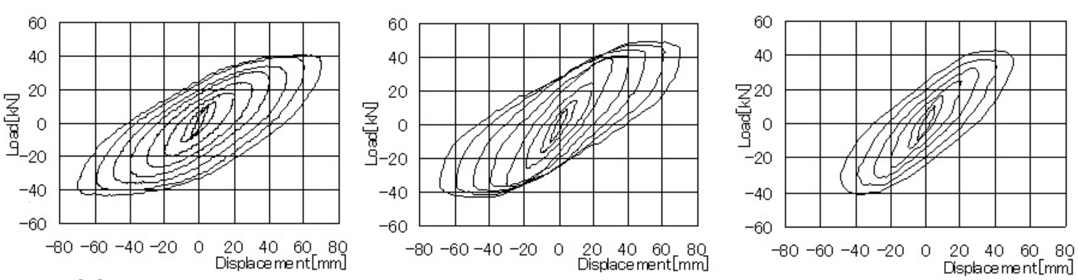


Fig. 12 Experimental model of umbrella shaped damper system (unit:mm)

The loading tests was carried out by actuatar attached a steel beam (H-$250\times250\times9\times14$) at the top of timber frame.

The relations between lateral load and displacement of top of the frame is shown in Fig. 13, which observed by the dynamic loading tests for loading periods of 3.0 seconds, 1.0 seconds, and 0.5 seconds.

It was found that all of the hysteresis loop is stable in any loading periods. Equivalent stiffness and equivalent viscous damping factor are computed from those results, and which are plotted for the loading periods in Figs. 14 and 15. It was found that both values have the dependence for the amplitude and the loading periods in those figures. Moreover, the equivalent viscous damping factor is about 68% at the maximum, and having high damping performance was shown.



(a) 3.0 sec **(b) 1.0 sec** **(c) 0.5 sec**

Fig. 13 Hysteresis loop by harmonic load

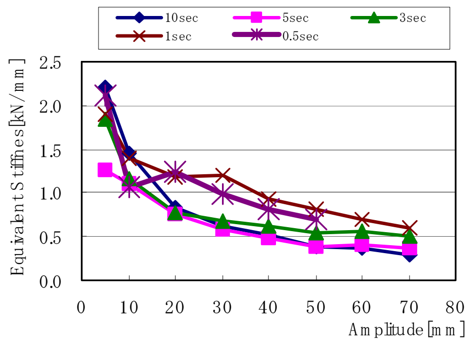


Fig. 14 Relations between equivalent stiffness and maximum loading amplitude

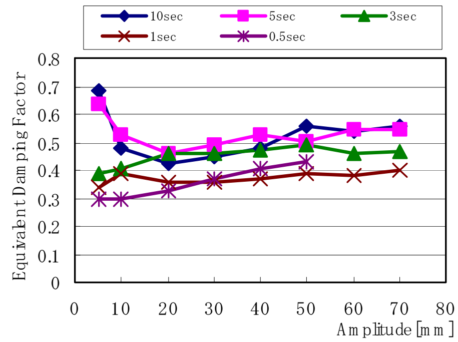


Fig. 15 Relations between equivalent damping factor and maximum loading amplitude

THE FIRST APPLICATION OF TENSILE TOGGLE DAMPER SYSTEM TO JAPANESE TRADITIONAL TIMBER STRUCTURES

This section describes the example which applied tensile toggle damper system to a Japanese traditional timber structure. The structure is a use of temple, which was built in 1767. The appearance photograph of the structure is shown in Fig. 16, and a plan and sectional drawing are shown in Figs. 17-19. The structure height from a foundation stone is 12.9m, the floor space of a main structure is about 250 square meter. The earthquake resisting elements of the structure are the frame arranged around the main structure and eight columns(ϕ 300mm) arranged in the center part of it. The frame consist of 20 columns(240mm square) and beams (250mm$\times$325mm).

Fig. 16 The front appearance of the structure installed in the system

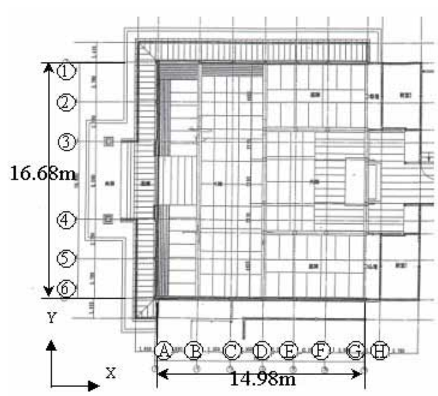


Fig. 17 Plan of the structure

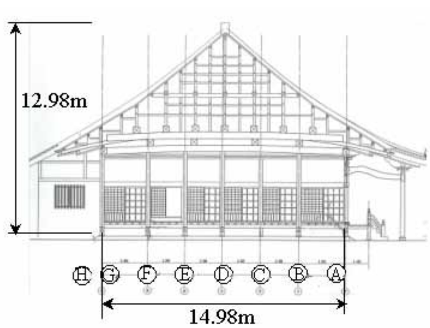


Fig. 18 Section for X-direction of the structure

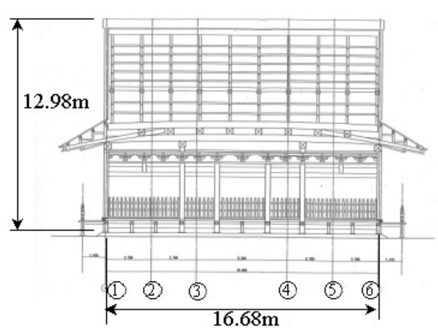


Fig. 19 Section for Y-direction of the structure

The results of micro tremer observation before retrofitting is shown in Fig. 20. Installation of a micro tremer meter is on the beam of the roof truss. In this observation, it was found that the primary period is 0.76 seconds as swaying mode for Y-direction, the secondary period is 0.62 seconds as swaying mode for X-direction, and the 3rd period is 0.45 seconds as torsional mode. Considering of the height of this structure, it will be thought that about 0.5 seconds is desirable as the period of the first mode.

The tensile toggle damper systems are installed in the new frame constructed in pararell with the old frame. The old and the new frame have connected at three places of a top, a middle, and a bottom of columns with penetration bolts(ϕ16mm) through steel plates(a thickness of 12mm).The arrangement of the tensile toggle damper system is shown in Fig. 21. 40 sets of the devices are installed.

In this retrofitting, although the damping wall called as "Kame-Kabe" is installed in parallel with the tensile toggle damper system.(Refer to reference Ishigaki [1] for details of it.)

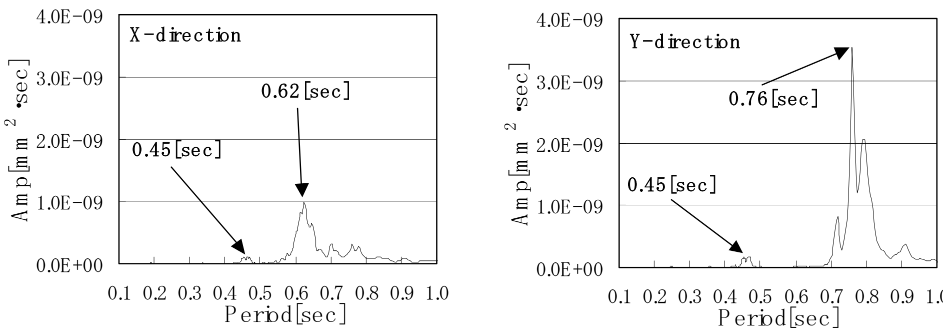


Fig. 20 The results of micro tremor observation for the structure before retrofitting

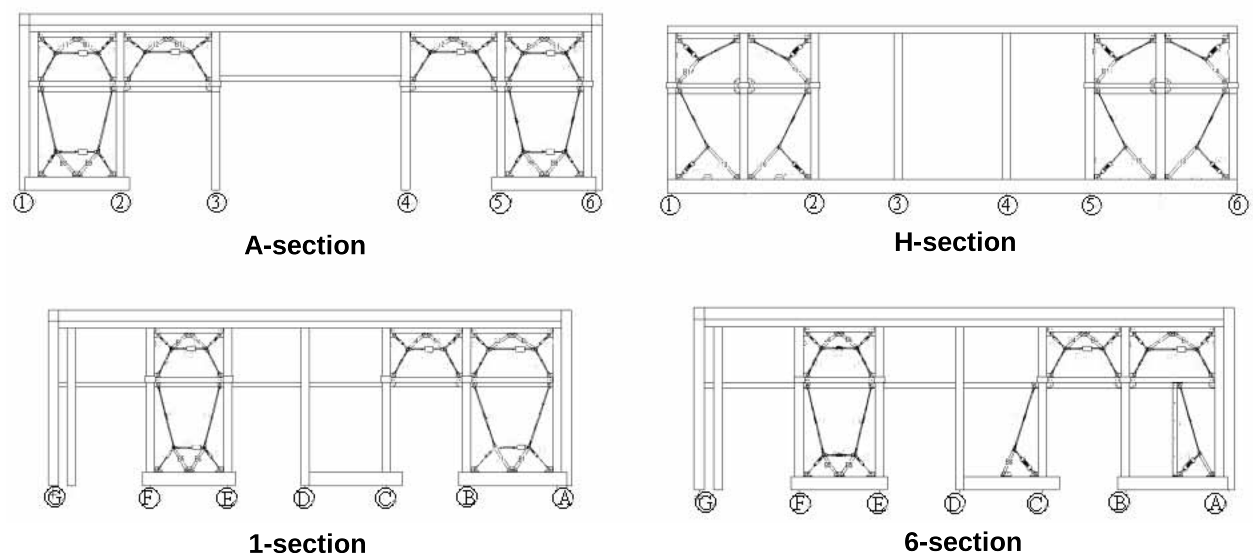


Fig. 21 Sectional drawings of the frames installed in the tensile toggle damper systems

The transfer function observed by micro tremor measurement after retrofitting is shown in Fig. 22. In this observation, It was found that the first period for Y-direction is 0.45 seconds, and the second period for X-direction is 0.4 seconds. In this results show clearly that the design periods for retrofitting was achieved.

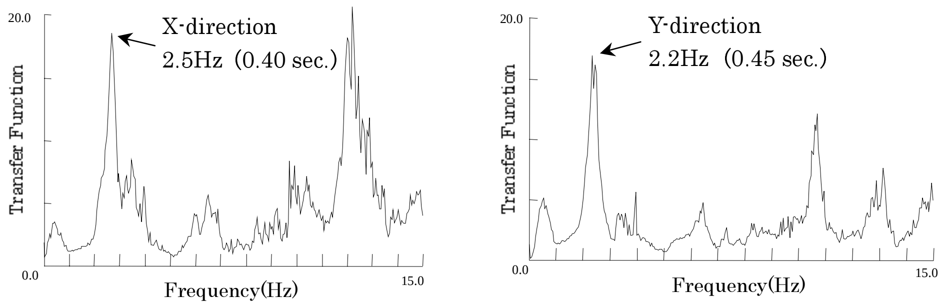


Fig. 22 The results of micro tremor observation for the retrofitted structure

Next, the result of having researched the damping performance for the earthquake is described. In computing response analysis, the three dimensional analysis model is used, which is composed of the structural elements except roof-truss elements. That analysis model is shown in Fig. 23. The results of eigen value analysis in this model is obtained that the first natural periods is 0.48 seconds as swaying mode for X-direction, the second periods is 0.47 seconds as swaying mode for Y-direction, and the 3rd periods is 0.37 sec as torsional mode. In addition, the results of complex eigen-value analysis is obtained that viscous damping factor at the first mode is 13.6%, and the second mode is 17.2%.

Next, the results of earthquake response analysis is described. The ground excitation used in this analysis is shown in Table 1. The components of those waves are El-Centro 1940 NS, Taft 1952 EW, Hachinohe 1968 NS, and Takatori 1995 EW, and the maximum acceleration of those waves are magnified so that the maximum velocity become 50 cm/sec except Takatori EW. The results of step by step elatoplastic simulation is shown in Table 1. The values of the table show the maximum response values of all nodes in this model. The maximum displacement value is 5.9 cm in the case of Takatori EW. It is shown clearly that this retrofitted structure have high energy absorption performance for the earthquake, because the result of analysis in before retrofitting model was 14.6 cm of the maximum value in the same wave.

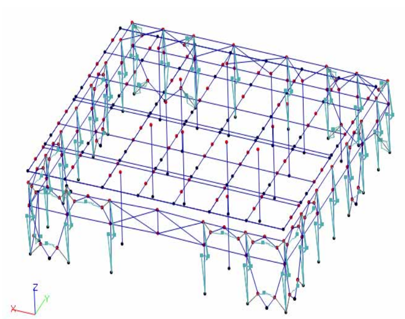


Fig. 23 Three dimensional analysis model

Table 1 Analysis results of step by step response analysis

Input Earthquake	The maximum acceleration (cm/sec^2)	Input Direction	The maximum response value		
			Acc. (cm/sec2)	Vel. (cm/sec)	Disp. (cm)
El-Centro 1940 NS (Max.Vel 50 cm/sec)	511	X	935	73	5.4
		Y	966	74	5.4
Taft 1952 EW (Max.Vel 50 cm/sec)	497	X	945	70	5.7
		Y	857	66	5.2
Hachinohe 1968 NS (Max.Vel 50 cm/sec)	330	X	531	37	2.9
		Y	554	35	2.8
JR-Takatori 1995 EW	656	X	979	58	5.7
		Y	916	56	5.9

THE SECOND APPLICATION OF UMBRELLA SHAPED DAMPER SYSTEM TO JAPANESE TRADITIONAL TIMBER STRUCTURE

This section describes the example which applied the umbrella shaped damper system to other traditional timber structure. The structure was built 300 years ago, which is preserved by constructing the structural glued laminated timber frames newly around the old frames. The new frames are installed in the umbrella shaped damper system.

The appearance of the structure is shown in fig. 24 and the photograph of the roof truss inside the structure is shown in fig. 25.

Fig. 24 Appearance of the structure installed in the umbrella shaped damper system

Fig. 25 The Japanese roof truss of the structure built in 300 years ago

The building plan and sectional drawings are shown in Figs. 26 and 27. The columns of the laminate timber frame consist of two elements at a point. And the old frame is fixed between the two columns at that point. (refer to Fig. 26)

The roof is consists of copperplate, and all loads are supported by the new frame of laminated timber.

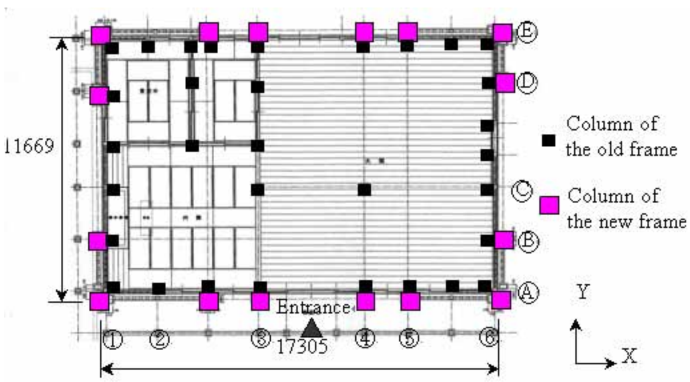
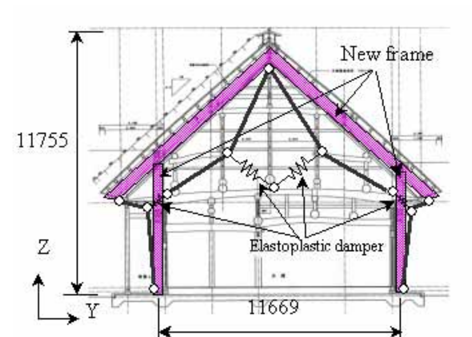


Fig. 26 Plan of the structure (unit:mm)



(unit:mm)

Fig. 27 Section for Y-direction of the structure

The umbrella shaped damper systems are installed in the new frame. Also the elastoplastic dampers with tensile toggle dampers are installed in the roof truss, what is the purpose of increasing rigidity.

The arrangement of umbrella shaped damper system is shown in Fig. 28.

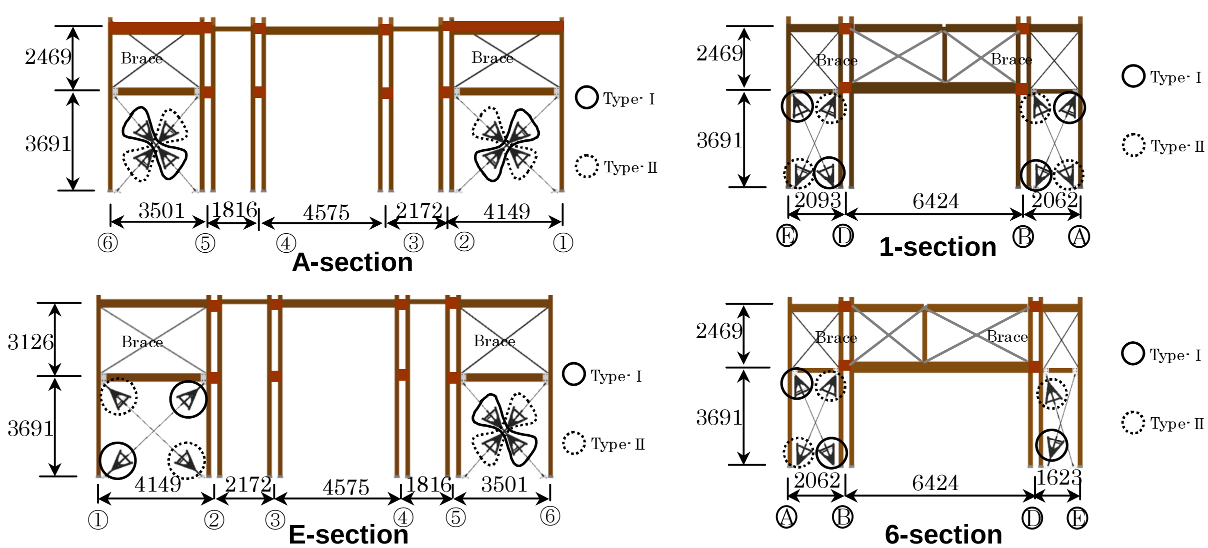


Fig. 28 Sectional drawings of the frames installed in the umbrella shaped damper systems

The installed umbrella dampers are two types of the devices. The one is the oil damper with coil shaped spring in the foregoing paragraph (called Type-I), the other is the coil shaped elastoplastic damper (called Type-II). The details of the coil shaped elatoplastic damper are described by reference Kurabayashi [2]. In addition, both the form and the size of the umbrella damper are the same as the experimental model used in the loading tests of the foregoing paragraph. The number of installation of the umbrella damper is 30 sets in all.

In order to research on the performance for the earthquake of this structure, the elastoplastic response analysis was performed using three-dimensional analysis model shown in Fig. 29. The analysis model is modeled only the portion of the new frame, and which node is given the concentrated mass of the old frame.

The result of the eigen-value analysis showed that the first periods is 0.46 seconds as swaying mode for Y-direction, the second periods is 0.38 seconds as swaying mode for X-direction with a little torsion, and the 3rd mode is also swaying mode for X-direction with a little torsion as 0.34 seconds. In addition, it was found that the damping factors have obtained the value of 31% as the first mode and 22% as the second mode by the complex eigen-value analysis.

Next, the result of having performed elastoplastic seismic response analysis is shown in Table 2. The earthquake used for analysis were the same wave showed Table 1 in the beforegoing paragraph. The response values shows the maximum response value in all nodes. The maximum displacement value is 6.3cm (equal to column rocking angles of 1/108) in the case of Takatori 1995 EW. That result shows that this structure have the high performance for the earthquake.

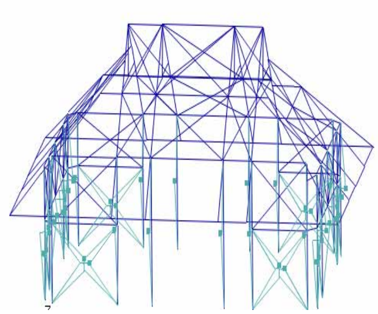


Fig. 29 Three-dimensional analysis model

Table 2 The results of step by step response analysis

Input earthquake	The maximum input acc. (cm/sec2)	Input direction	The maximum response value		
			Acc. (cm/sec2)	Vel. (cm/sec)	Disp. (cm)
El-Centro 1940 NS (Max. Vel. 50 cm/sec)	511	X	571	34	3.5
		Y	583	40	4.6
Taft 1952 EW (Max. Vel. 50 cm/sec)	497	X	540	30	3.0
		Y	541	41	4.0
Hachinohe 1968 NS (Max. Vel. 50 cm/sec)	330	X	326	21	1.6
		Y	327	22	1.7
JR-Takatori 1995 EW	656	X	670	44	3.8
		Y	595	52	6.3

CONCLUSIONS

Two kinds of new damping devices applied toggle mechanism was developed, and the damping performance was studied by full scale dynamic loading tests. Consequently, it was found that those device had the high damping performance. And both devices were installed in two Japanese traditional timber structures. The seismic observation equipment is installed in the structure shown in Fig. 16. The behaviors of the structure will be studied when suspected future earthquakes occurred.

ACKNOWLEDGEMENTS

This research was conducted as a part of the Academically Promoted Frontier Research Program on “Sustainable City Based on Environment Preservation and Disaster Prevention “ at Nihon University, College of Science and Technology (Head Investigator: Prof. Ohtsu, I.) under a grant from the Ministry of Education, Science and Sports, Japan. This study was also supported by Nihon University Research Grant for Assistants and Young Researchers (2003). The authors wish to express their appreciation to all the members of this committee.

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