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Practical study on a new type Buckling-Restrained-Brace

Takanori OYA*, Takashi FUKASAWA[a], Makoto FUJIWARA[a], Yoshihiko KUROIWA[a] and Jun ARAI[a]

*Tomoe Corporation
4-5-17, Kachidoki Chuo-ku, Tokyo, 104-0054, Japan
t_ooya@tomoe-corporation.co.jp

[a] Tomoe Corporation

Abstract

A number of a new type Buckling-Restrained-Brace (T-BRB) using steel mortar planks have been applied to various structures (spatial structures, steel bridges and steel towers) as well as multi-story buildings. The brace has two buckling restraining parts (steel mortar planks), clipping a core plate being under axial forces. These parts are welded together and restrain the core plate of plastic behavior, avoiding the out-of-plane deformation and the buckling. The size of steel mortar plank can be designed corresponding to energy absorption demands, irrespectively the sizes of both end-connections. This paper introduces the applications of a new type BRB to various structures.

Keywords: buckling-restrained brace, steel mortar planks, damper, seismic retrofit, bridges, school gymnasium.

1. Introduction

T-BRB is a new type of Buckling-Restrained Brace (BRB) shown in Figure 1. This buckling-restrained brace has two buckling restraining parts (steel mortar planks), clipping a core plate being under axial forces. These parts are welded together and restrain the core plate of plastic behavior, avoiding the out-of-plane deformation and the buckling.

This buckling-restrained brace is the one developed by Iwata *et al*. [1], and the one was put into practical use through a lot of examinations for performance evaluation. The results of a series of performance tests were reported in Yamashita *et al*. [2].

This paper introduces the features of T-BRB and some cases to which T-BRBs are applied.

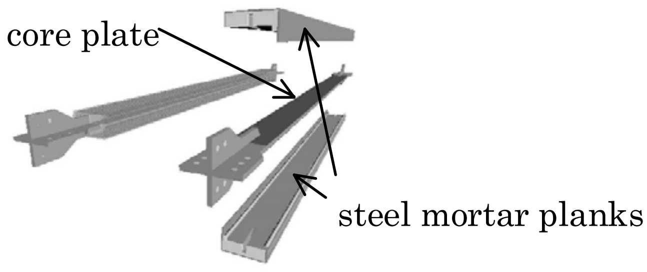


Figure 1 : T-BRB (Buckling-restrained brace using steel mortar planks)

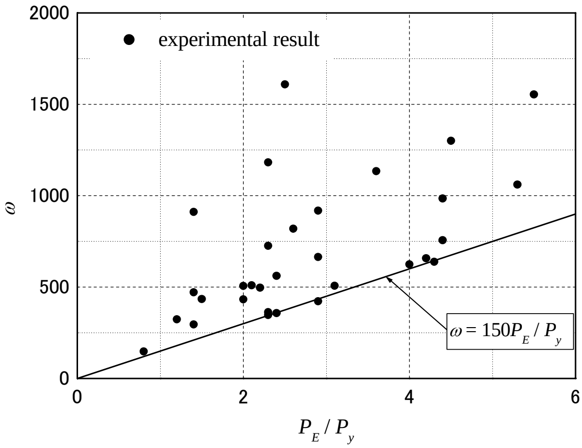


Figure 2 : Relationship between energy absorption capacity and rigidity of buckling restraining part

2. Features of T-BRB

The size of the buckling restraining part of a type of BRB filling mortar with steel pipe is decided depending on the size of the joint.

On the other hand, the size of joint doesn't influence the size of the buckling restraining parts of T-BRB, because T-BRB is a type clipping the core plate with two buckling restraint parts. Moreover, there is a correlation strong in ω , the index of energy absorption capacity, and P_E / P_y, the index of rigidity of the buckling restraining part, as shown in Figure 2. P_E is Euler buckling load and P_y is the yield strength of the core plate. The index of energy absorption capacity ω is defined by following equation.

$$\omega = \frac{W}{P_y \cdot \delta_y} \qquad (1)$$

where W is the total energy that T-BRB absorbs and δ_y is the yield deformation in axial direction of the core plate.

Therefore, the buckling restraining part can be designed corresponding to energy absorption demands. This feature makes it possible that a brace is thined and is lightened under a certain condition (as shown in Figure 3).

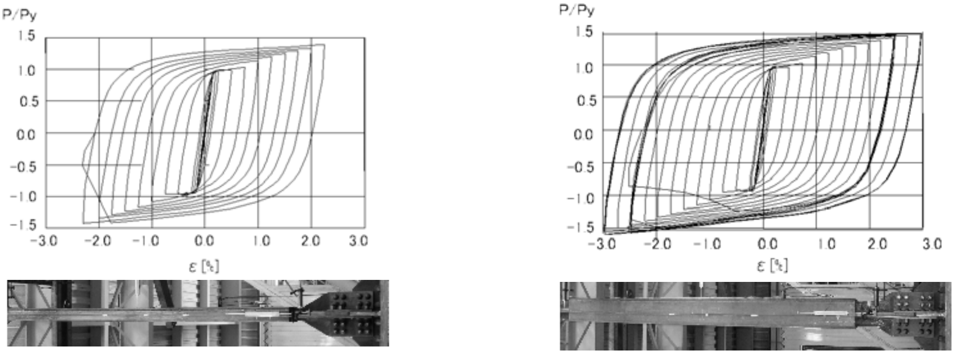
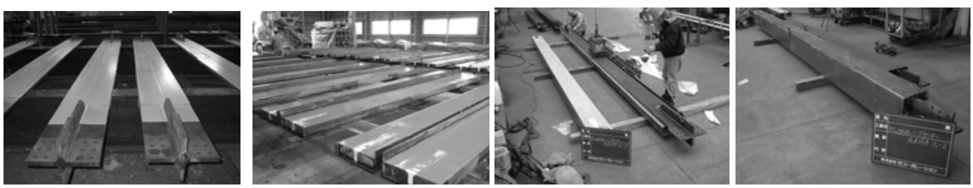


Figure 3 : Relationship between steel mortar plank size and energy absorption performance

3. Production of T-BRB

The production procedure of T-BRB is shown in Photo 1.



(1) (2) (3) (4)

Photo 1 : Production procedure of T-BRB

(1)Core plate sealed unbonding material, (2)Production of steel mortar planks, (3)Setting coreplate to steel mortar plank, (4) Completion

4. Application to various structures

A number of BRBs are applied to various structures. Although BRBs are applied generally to the multi-story buildings as damper or aseismic brace, they are used also as damper of a new bridge and used as reinforcing member in seismic retrofit of a school gymnasium or the communication wireless steel tower (Takeuchi et al. [3]).

In the following, two examples are introduced that T-BRBs are applied to a new bridge as damper and used as reinforcing member in seismic retrofit of a school gymnasium.

4.1. Application to rigid-frame bridge

In Japan, the chapter of an earthquake-proof design of specifications for highway bridges was revised starting with Kobe earthquake in 1995. As a result, securing seismic performance of bridges for huge earthquakes was obligated. Therefore, the examinations based on dynamic analysis came to be done to existing bridges, but bridges those do not satisfy a prescribed seismic performance are not few.

It is assumed that increasing sectional area a general method of reinforcement. But there are problems such that the site construction scale becomes large or the reaction force of the substructure increases because the dead load increases.

The result of review about applying dampers to diagonal members for arch bridge as a method of improving seismic performance is reported by Inoue *et al*.([4]). In the report, the method can greatly decrease the weight of the reinforcement steel members comparatively easily.

According to the report about the above road type Langer bridge, because the steel damper yielding to bending force needs the clearance for the temperature expansion, and because the oil damper cannot expect resistance for late deformation such as the expansions of the temperature, and is expensive and needs regular maintenance, the steel damper yielding to axial force (= buckling-restrained brace) is relatively effective. Moreover, the conclusion is put that the improvement the seismic performance with damper is very effective economically, because dead load added can be reduced, construction becomes relatively small scale, and the term of works can be shortened.

The bridge (Araku-bashi bridge) shown in Photo 2 and Figure 4 is a case where the method of the above-mentioned is applied. The outline of the object bridge is shown in Table 1.

Photo 2 : The Bridge
to which T-BRB is applied

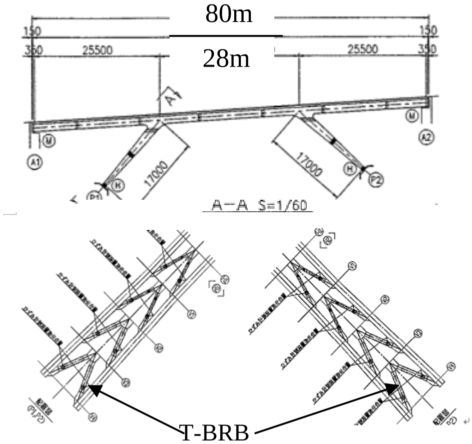


Figure 4: Layout of T-BRB

Table 1 : Outline of the object bridge and T-BRB

Bridge Name	Araku-bashi		
Production (Bridge)	Sakurada Co., Ltd.		
Construction	JFE Engineering Corporation		
Construction Term	2006.8-2008.3		
Structural Type	Rigid-frame bridge with knee brace		
Bridge Scale in Length	80.0m (28.0m between the fulcrums)		
T-BRB	Core Plate	Yield Strength	Ammount
	LY225, t=28mm	2,000kN	8
	LY225, t=28mm	1,000kN	8

4.2. Application to seismic retrofit of school gymnasium

Recently, the seismic retrofits of the schoolhouses are actively enforced in Japan. For a lot of school gymnasium, which might be used as refuges after earthquake disasters, seismic diagnosis and seismic retrofit are similarly enforced.

The gymnasium shown in Figure 5 is an example of applying the buckling-restrained brace to the seismic retrofit of the school gymnasium that has a single layer cylindrical latticed shell roof with truss arches at the both gable ends. The roof structure is called the diamond shell structure.

The outline of the object gymnasium is shown in Table 2.

Table 2 : Outline the object gymnasium and T-BRB

Construction year	1978		
Reinforcement year	2007		
Roof structure	Diamond shell		
Substructure	Moment frame with truss beam (in the span dicrection) Braced frame (in the longitudinal direction)		
Structure scale	$18.2m(span)\times 32.55m$		
T-BRB	Core Plate	Yield Strength	Ammount
	SN400B, t=9mm	120kN	4 (in the span direc.)
			2 (in the longitudinal direc.)

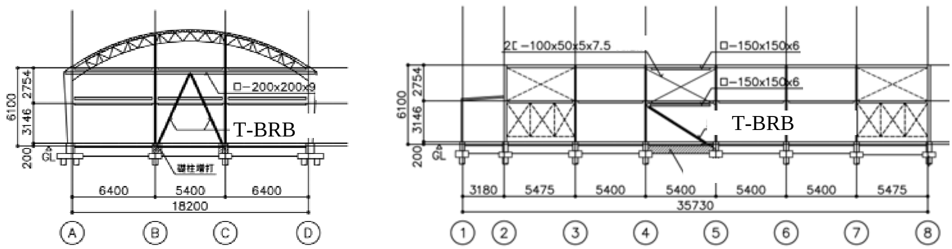


Figure 5 : The gymnasium reinforced using T-BRB

Photo 3 : The gymnasium after reinforcement

4.2.1. Result of seismic diagnosis

Generally based on the standard in Japan for seismic diagnosis, a seismic performance index of structure, I_S , is used, and it is expressed as follows.

$$I_S = C \times F \qquad (2)$$

where C : Strength index (yield shear coefficient), F : Ductility index.

Therefore, a seismic performance of structure is evaluated high when the structure has high ductility even if it has low strength.

The ductility index of members is provided according to the failure pattern [5]. For example, F value 1.3 must be adopted when the ultimate strength of structure is decided by fracture of the brace joint.

In seismic diagnosis, after confirming that the horizontal force can be transmit through the roof structure to the substructures, the seismic performance is evaluated by ultimate strength of the structure assuming that it consists of two moment frames with truss beams in the span direction and consists of two layers braced frames in the longitudinal direction.

In the span direction, the failure pattern is the buckling of the truss member and the yield of the column foot by bending. On the other hand, the failure pattern is the fracture of brace joint in the longitudinal direction. The result of seismic diagnosis is shown in Table 3.

The seismic performance doesn't satisfy the target values in the both direction.

Table 3 : The results of seismic diagnosis for original and reinforced structre

Direction		Target	Original		Reinforced	
		I_{S0}	I_S	Judgement	${}_RI_S$	Judgement
Span direc.		0.7	0.28	NG	0.85	OK
Longitudinal direc.	Upper Layer	0.7	0.52	NG	1.25	OK
	Lower Lyaer	0.7	0.52	NG	0.84	OK

4.2.1. Outline of reinforcement using T-BRB

The ductility index of BRB can be applied high value because BRB has excellent ductility and energy absorption capacity. In a word, the necessary strength of the whole structure can be suppressed in the seismic performance evaluation based on equation (2). Using BRB, the reinforcement of the roof truss becomes unnecessary and the number of braces for reinforcing can be decreased.

The reinforcement of this structure (as shown in Figure 5) is executed according to the sequentes. The seismic performance of the reinforced structure is shown in Table 3.

< In the span direction >

1) The beams are installed in the capital level and four T-BRBs (yield strength=120kN, core plate : t=9mm, SN400B) are installed under the beams.
2) The reinforcing members and the joints are designed by using the design force 1.7 times the yield strength of the BRB in consideration of the strain hardening.
3) The ultimate strength of the structure is calculated at the time when the BRB yields. In calculating the structural seismic capacity index, F=3.3 is adopted as the ductility index.

< In the longitudinal direction >

1) In the upper layer, two channel braces are arranged in X shape. On the other hand, in the lower layer, two T-BRBs (yield strength=120kN, core plate : t=9mm, SN400B).
2) The beams are installed to inside steps and the highest rung for the brace installation.
3) The strength of existing braces is treated as zero, though there are not removed.
4) The ultimate strength of the upper layer is calculated at the time when the joint of brace fractures. The one of the lower layer is calculated at the time when the BRB yields. In calculating the seismic performance index of structure of upper layer, F=1.3 is adopted as the ductility index. In calculating the one of lower layer, F=3.3 is adopted as the ductility index.

5. Summary

This paper introduced the application of a new type of the buckling–restrained brace to a new rigid-frame bridge and a seismic retrofit of the school gymnasium. Besides these cases, T-BRBs are applied toseismic retrofits of the communication steel towers. In such case, although it is necessary to reduce the wind receiving area, T-BRB that can design the size of the restraining part according to the performance will be effective.

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