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Seismic Brace Using Aramid Fiber Rope to Retrofit Building

*[1] Natsuki Yasui, [1] Kaidoh Yamaguchi and [2] Osamu Takahashi
[3] Kaori Tsukano and [3] Yoshinori Tateoka
[1] Graduate Student, Dept. of Architecture, Tokyo University of Science, Japan
[2] Professor, Dept. of Architecture, Tokyo University of Science, Japan
[3] Sanwa Tekki Corporation, Japan

Abstract

In this paper, a seismic brace using an aramid fiber rope is introduced so that a building can easily be retrofitted in a short period of time. For this seismic brace, the aramid fiber rope is connected to structural member of the building by a wedge type fitting. The wedge shape of this connection fitting is optimized to avoid stress concentration on the fiber rope. Moreover, the workabilities for assembling the fiber rope to the connection fitting at the construction site, which includes the unraveled fiber degree and the deviation of the fiber density at the rope end, are investigated. Finally, the developed seismic brace is attached to a wooden frame and load bearing wall tests are carried out. Through experimental results, the effect of the seismic brace using the aramid fiber rope is confirmed. Also, points to be noted when assembling the fiber rope at the construction site become clear.

Key words: Seismic brace, Fiber rope, Connection fitting, Tensile strength

1. Introduction

Demands for high performance fibers have been expanded due to needs of energy and resource saving, safety and environmental issues. New materials such as chemical fibers, polymeric materials, etc. have recently been used as materials for buildings. However, high performance fibers are not yet fully utilized as structural materials. General structural materials are still wood, concrete, steel and so on. Before an earthquake occurs, quick and low cost retrofit is desired so as that serious damages can be reduced. We have studied that the high performance fibers can be utilized as the building structural materials [1] [2]. In this paper, it is described that a seismic brace using an aramid fiber rope can easily retrofit a building in a short period of time.

2. Connection Fitting

2-1. Aramid fiber rope

The aramid fiber is an aromatic polyamide fiber produced by organic chemical synthesis. The aramid fiber has higher tensile strength than natural and general synthetic fibers. For this research, a para-aramid fiber (in detail, a co-poly-paraphenylene/3,4'-oxydiphenylene terephthalamide, hereafter is called 'Technora') is used [3]. Technora is made from copolymers and developed by Teijin Limited. It has high tensile strength and excellent resistance to heat and chemicals, especially acids and alkalis. Thus, it is used in rubber reinforcement, ropes, protective

*Corresponding author: Address: Department of Architecture, Tokyo University of Science, 6-3-1 Niijuku, Katsushika, Tokyo 125-8585, Japan, E-mail address:

goods, cement and plastic reinforcement and many industrial applications.

For example, Technora is 8 times stronger than steel. This property will result in significant weight reduction. Technora has high resistance to acids, alkalis and organic solvents. It also shows good hydraulic resistance. Thus, this fiber can be used outdoors and/or in combination with concrete. Focusing on high tensile strength and chemical resistance, a rope made of this high performance fiber can be applied for the seismic brace to retrofit the building. Figure 1 shows a configuration of the fiber rope, which is formed by knitting many bundles of the twisted fiber yarns.

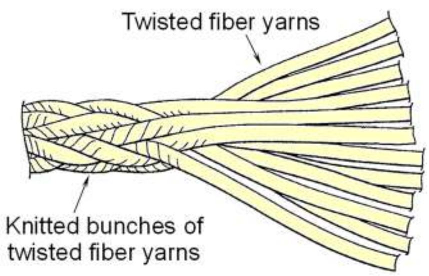


Figure 1. Configuration of high performance fiber rope

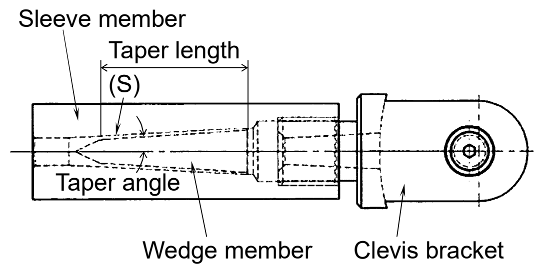


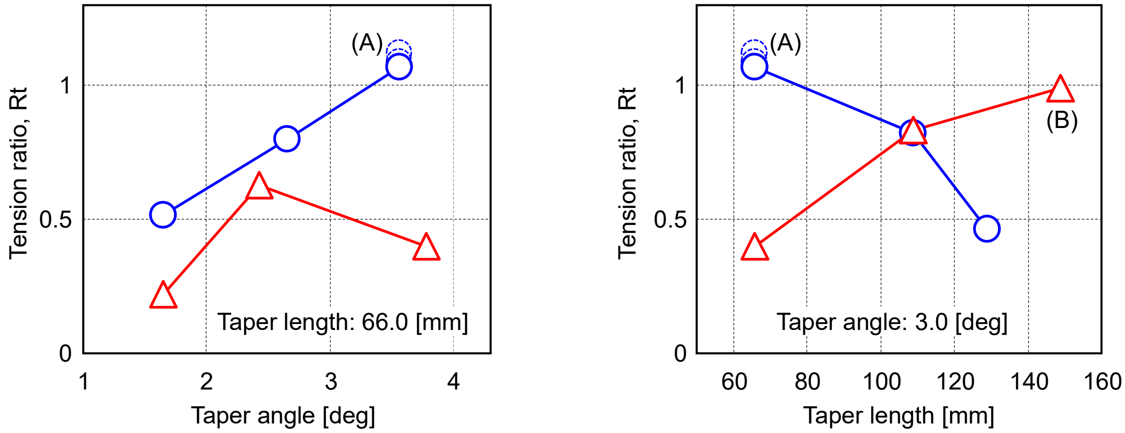
Figure 2. Wedge type connection fitting

2-2. Wedge type connection fitting

One of important technologies to apply the fiber rope for the seismic brace is to firmly connect the fiber rope to the structural building members. Since the aramid fiber is hard to be plastically deformed and the repulsive force when compressed is very small, the sufficient frictional force cannot be obtained by a compression fitting, which is usually used for steel wires and so on. Therefore, a wedge type connection fitting is adopted so that the fiber rope can securely be gripped and does not slip out of the fitting. Figure 2 shows an outline of the wedge type connection fitting. The wedge type connection fitting is composed of a wedge member, a sleeve member, and a clevis bracket. For this connection fitting, the fiber rope is disposed between the sleeve and wedge members, and is gripped without slipping due to the wedge effect.

2-3. Optimization of wedge shape

Within the wedge mechanism, it is necessary that the stress on the fiber rope should be equally distributed. If stress concentration occurs at a certain portion of the fiber rope, the fiber rope may be broken at that portion even when a load is lower than the original strength of the fiber rope. A taper angle of the wedge member is slightly larger than that of the sleeve member so that the wedge effect is reliably obtained. For this reason, the stress concentration can occur around the tip of the wedge member, which is shown by the portion (S) in figure 2. The wedge shape is optimized based on the experiments so that the fiber rope can generate its original strength. As design parameters of the wedge shape, the taper angle and length are focused on. Figure 3(a) shows experimental results for varying the taper angle under the taper length of 66.0 mm. Figure 3(b) is results for varying the taper length under the taper angle of 3.0 deg. The fiber ropes, whose nominal loads are 50 kN and 100 kN, are used for these experiments.



(a) Varying taper angle (b) Varying taper length

Figure 3. Tensile strengths based on wedge shape

The tension ratio 'Rt' on the vertical axis of graphs indicates a ratio between the assembly breaking load (i.e., the breaking load while the fiber rope is assembled with the connection fitting) and the strength of the fiber rope itself. In other words, 'Rt = 1' means that the assembly breaking load is equal to the original strength which the fiber rope has. Therefore, 'Rt is close to 1' is set as a target.

Within the experimented ranges of the design parameters, the fiber ropes of 50 kN and 100 kN show different tendencies. For example, Rt increases with increasing taper length for the 100 kN rope. On the other hand, Rt decreases with increasing taper length for 50 kN rope. This fact indicates that there are different optimum conditions in each fiber rope.

For the 50 kN rope, the target is satisfied with the wedge shape under the condition shown in (A). Two additional experiments are conducted under the same condition to eliminate the influence of error and ensure the results. Here, the results are indicated by dot lines. In any cases, the fiber ropes break outside the connection fitting. It is confirmed that the condition (A) is the optimum condition of the 50 kN rope to avoid the stress concentration.

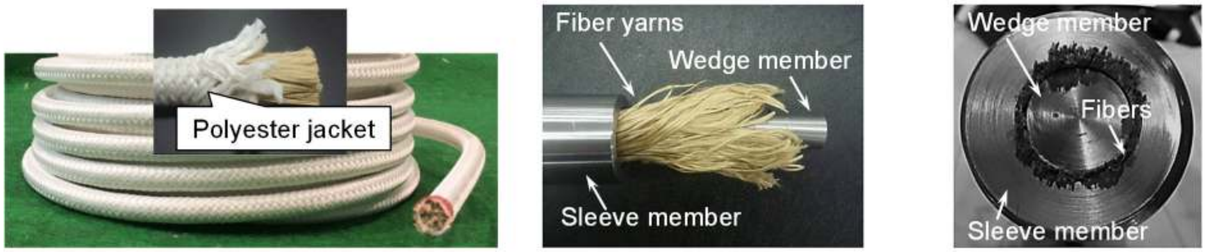
For the 100 kN rope, Rt is close to 1 under the condition shown in (B). However, the fiber rope breaks inside the connection fitting in the condition (B). Therefore, the optimum condition of the 100 kN rope seems to be close to the condition (B).

3. Investigation of Workabilities

3-1. Assembling process

Even though the fiber rope has high tensile strength, it is lightweight and flexible. The fiber rope wound in a coil shape and the connection fitting are carried separately to the construction site. Then, they are assembled there. Figure 4 shows a process in which the fiber rope is joined with the connection fitting. For the fiber rope, the knitted fiber bundles are covered with a polyester jacket. Assembling is performed according to the following procedure:

(1) The fiber rope is cut to the necessary length for the seismic brace at the construction site (see



(a) Wound fiber rope to carry (b) To insert unraveled fiber yarns (c) To eliminate extra fibers

Figure 4. Assembling process of fiber rope

figure 4(a)).

(2) The jacket texture at the rope end is peeled off and the fiber yarns are loosened.

(3) The loosened fiber yarns are inserted into the sleeve member.

(4) The fiber yarns are arranged uniformly around the hole of the sleeve member. Then, the wedge member is driven into the hole (see figure 4(b)).

(5) Extra fibers at the rope end are eliminated (see figure 4(c)).

3-2. Fiber treatment at rope end

As above-described for the fiber rope, after the fiber yarns are twisted as the bundles, pluralities of the bundles are knitted. It is investigated how the fiber treatment at the rope end (i.e., the degree of loosened fiber yarns) affects the tensile strength while assembling the fiber rope to the connecting fittings. As shown in figure 5, the following three loosened states are compared:

(a) First is a state where the fibers are still knitted and twisted. Hereinafter, it is referred to as the ‘knitted state’.

(b) Second is a state where the fibers are still twisted although they are unknitted. Hereinafter, it is referred to as the ‘twisted state’.

(c) Third is a state where the fibers are completely unraveled. Hereinafter, it is referred to as the

(a) Knitted state

(b) Twisted state

(c) Unraveled state

Figure 5. Degree of loosed fiber yarns

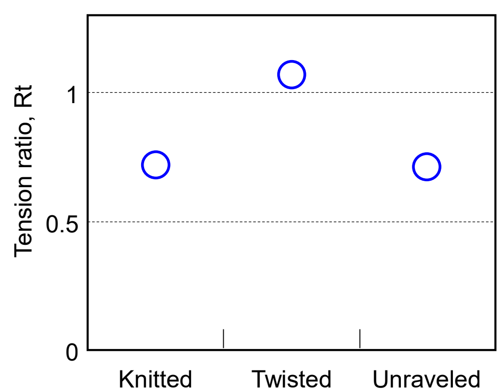


Figure 6. Tensile strengths based on fiber treatment

‘unraveled state’.

Tension tests are carried out using the 50 kN rope. For the tests, the wedge shape of the connection fitting is same as the above-described condition (A). Figure 6 shows the results in three different states of the fiber treatment. The tensile strength of the twisted state is higher than that of the unraveled state. A new knowledge is obtained that high tensile strength can be secured by leaving the twists of the fiber yarns.

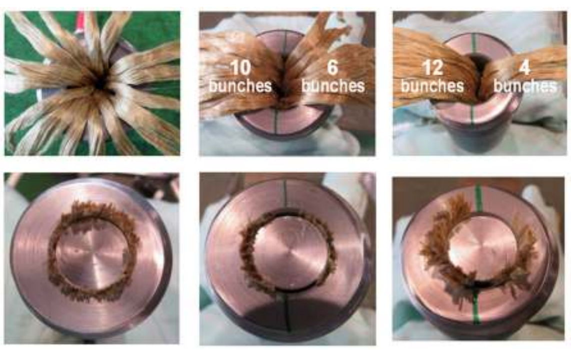
3-3. Deviation of fiber density distribution

A distribution of the fiber density should be uniform within the sleeve of the connection fitting. However, uneven distribution of fiber density may occur when the fiber rope is assembled with the connection fitting. It is investigated how the deviation of the fiber density distribution affects the tensile strength. The fiber rope used for this investigation consists of 16 twisted fiber bundles. Experiments are conducted in the following three cases. As shown in figure 7, the 16 twisted fiber bundles are arranged uniformly or non-uniformly.

(a) The 16 fiber bundles are evenly arranged. Hereinafter, it is called the ‘even state’.

(b) The 10 fiber bundles on one side and the 6 bundles on the other side. Hereinafter, it is called the ‘bias 10:6’.

(c) The 12 bundles are on one side and the 4 bundles on the other side. Hereafter it is called the ‘bias 12:4’.



(a) Even state (b) Bias 10:6 (c) Bias 12:4

Figure 7. Deviation of fiber density distribution

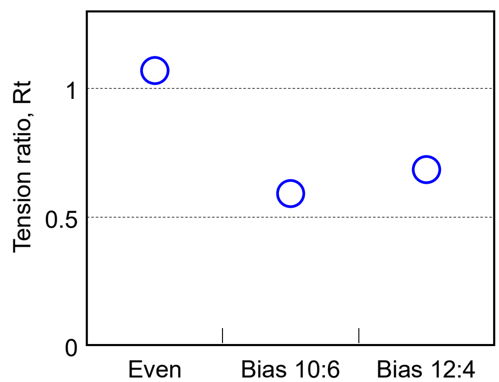


Figure 8. Tensile strengths based on deviation of fiber density distribution

Figure 8 indicates experimental results on the deviation of the fiber density distribution. The experimental conditions are same as the above-mentioned condition (A). If there is a bias in the fiber density distribution, the tensile strength extremely decreases. Therefore, it is necessary to pay attention that the twisted fiber bundles are uniformly arranged around the sleeve hole and the wedge member is accurately driven into its center when assembling the fiber rope to the connection fitting.

4. Load-Bearing Wall Tests

4-1. Test conditions

Load-bearing wall tests are carried out to confirm the effectiveness of the developed seismic brace using the fiber rope. As shown in figure 9, a wooden frame is made of pillars of cedar and beams of douglas fir. A horizontal load is repeatedly applied in one direction to the wooden frame by the actuator. Experimental methods are based on 'Allowable Stress Design of Wooden Shaft Construction Housing, Chapter 2: Experiment Method and Evaluation Method of Each Part of Wooden Shaft Construction Housing, Section 1.2: Method of In-Plane Shear Experiment [4]'. The horizontal load is gradually increased in the multiple steps. When the load falls below 80% of its maximum value, or when the interlayer deformation angle becomes larger than 1/15 rad., an occurrence of breaking is judged. Here, the interlayer deformation angle is obtained by dividing the interlayer displacement by the frame height.

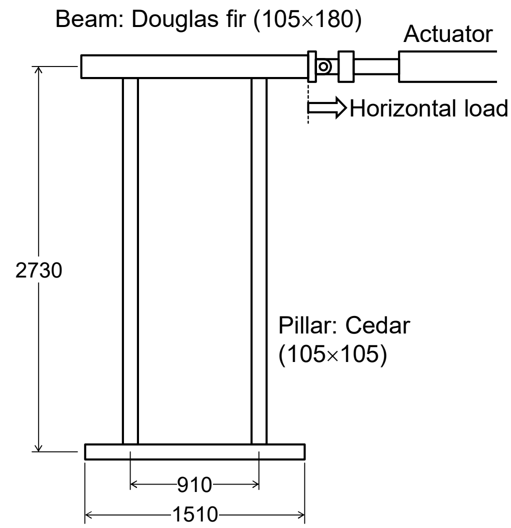


Figure 9. Configuration of load-bearing wall tests

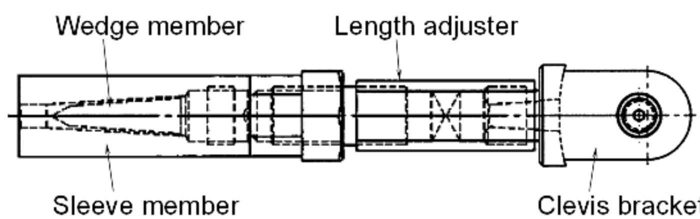


Figure 10. Connection fitting with length adjuster

The 50 kN rope is used for the experiments. An initial extension of 2 to 3 % is given to the fiber rope so that a tension is immediately generated right after the frame deformation occurs. The connection fitting with length adjuster, which is shown in figure 10, is used for adding the initial extension.

4-2. Test results and consideration

Figure 11 shows experimental results between the horizontal loads and interlayer deformation angles. For the wooden frame with the seismic brace, the break occurs at the pillar (see figure 12). In parallel with the experiment, simulation analyses are performed using the 'midas iGen (general analysis software)'. For the simulation analyses, it is assumed that the lower portion of the wood frame is rigidly supported and a horizontal load of 5.2 kN is applied to the upper beam of the wooden frame. Here, the applied horizontal load is the maximum load for the wooden frame without the seismic brace, which is obtained through the experiments. Figure 13 shows the simulation analysis results. Comparing the experimental and simulation results of the load-bearing wall tests with and without the seismic brace, it is indicated that the seismic brace can greatly decrease the deformation of the wooden frame. The effectiveness of reinforcement by the fiber rope is confirmed.

The wall magnification is calculated on the basis of the experimental results. The wall magnification is 0.5 in the case of only the frame and 1.0 when the seismic brace is applied. The wall magnification with the seismic brace is higher than that without the seismic brace. However, the wall magnification 1.0 is equivalent to the case where a wooden brace of 10 mm by 90 mm is used for the load-bearing wall by the wooden shaft assembly method. In other words, although the fiber rope is excellent in terms of construction workability, no special advantage in terms of performance is found comparing the conventional brace. As a cause, it may be conceivable that the displacement of the fiber rope becomes longer than necessary against the horizontal load. For the further studies, detailed analysis and improvement are necessary.

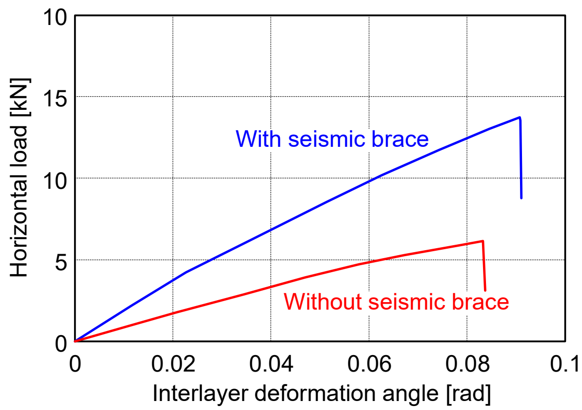


Figure 11. Experimental results between horizontal load and interlayer deformation angle

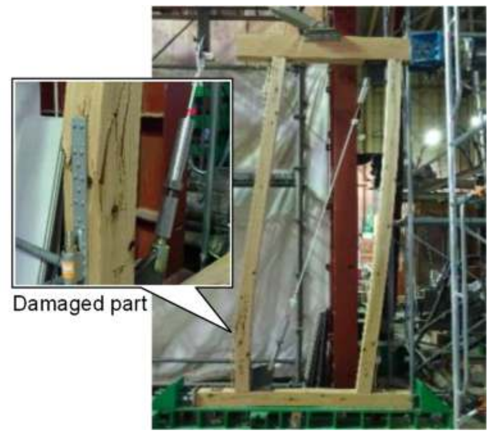
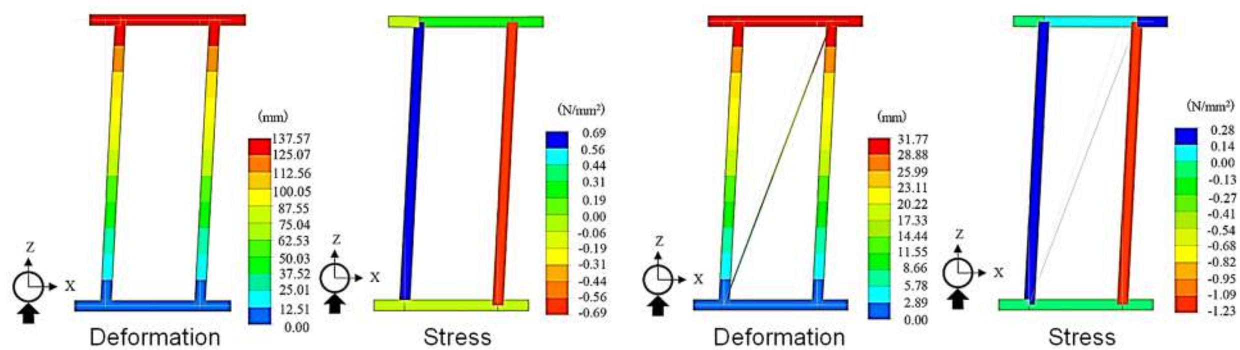


Figure 12. Wooden frame with seismic brace after destruction occurs



(a) Without seismic brace (b) With seismic brace

Figure 13. Simulation analyses of load-bearing wall tests

5. Summary

In this paper, a seismic brace using an aramid fiber rope is described. The key advantage of this seismic brace is to retrofit a building in a short period of time because it can easily be carried and handled.

The results obtained in this research are summarized below:

(1) A wedge type connection fitting to assembly the fiber rope with structural members is developed so that the fiber rope does not slip out. The wedge shape of the connection fitting is optimized to prevent the stress concentration on the fiber rope.

(2) Points to pay attention become clear when the fiber rope is joined with the connection fitting. The twists of the fiber yarns should be remained to maintain the tensile strength high. It is necessary that the twisted fiber bundles are uniformly arranged around the sleeve hole.

(3) The effectiveness of this seismic brace is confirmed through simulation and experimental results of the load-bearing wall tests.

For the future research, this seismic brace will be applied for actual buildings to improve the seismic resistant strength.

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