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ORIGINAL ARTICLE

Fixed–fixed flexural vibration testing method of actual-size bars for timber guardrails

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Abstract Resonance frequencies of bars with various types of end supports were examined in terms of flexural vibration. Sugi (Japanese cedar, *Cryptomeria japonica* D. Don) was used for the specimens. Small rectangular bars with dimensions of 25 mm (R) × 5 mm (T) × 300 mm (L), small round bars of 25 mm in diameter and 250 mm in length, actual-size rectangular bars with the dimensions of 45 mm (R) × 95 mm (T) × 1500 mm (L) and actual-size round bars of 180 mm in diameter and 2000 mm in length were made. Varying compression stress was applied to the parts around both ends of test specimen, whereupon flexural vibration tests were performed. The measured resonance frequency rose rapidly early in the increasing compression load process and was nearly stable for the larger compression load. The significant increases in the resonance frequency for round bars are thought to be derived from the wide area between the round bar and jig. It is necessary to compare the resonance frequency of a bar tightly fixed to a post with that of the same bar loosely fixed to the post.

Keywords End condition · Flexural vibration test · Round bar · Timber guardrail

Introduction

In 1998, timber guardrails were approved for use in national and prefectural roads provided they passed a collision test involving cars and trucks [1, 2]. Accordingly, various timber guardrails have been developed, whereby the total length of those actually used exceeded 50 km.

However, no method to determine the deterioration of lumber used for guardrails has yet been established, making it difficult to determine the replacement frequency for lumber. For this purpose, determining the change in strength of the lumber used for the timber guardrail over time is important.

In our previous work [3], a testing method of the flexural vibration test was investigated to measure appropriate strength properties with lumber assembled into construction because of the difficulty in placing or removing a load cell or torque meter on-site, whereupon the resonance frequencies of bars with various types of end supports were examined from flexural vibration. Rectangular bars with dimensions of 25 mm (radial, R) in width, 5 or 10 mm (tangential, T) thick and 300 mm (longitudinal, L) in length were used as the test specimens. Varying compression stress was applied to the parts around both ends of the test specimen and flexural vibration tests were performed. The measured resonance frequency rose rapidly early with the increasing load and approached the value of the fixed ends. Since perfect fixation of bar to post was difficult, not the resonance frequency itself but its temporal change will be an index indicating the degree of deterioration of a bar for a timber guardrail. The stable resonance frequency should be measured for fixing a bar to a post.

In the actual construction, however, the resonance frequency did not change dramatically (changed by only about 5%) when the bar was fixed to a post tightly or loosely [4]. This is considered attributable to the narrow contact area between the round bar and the flat plate (Fig. 1): in this system, a round bar comes in contact with the plate. A bolt installed at a post with 15 mm diameter

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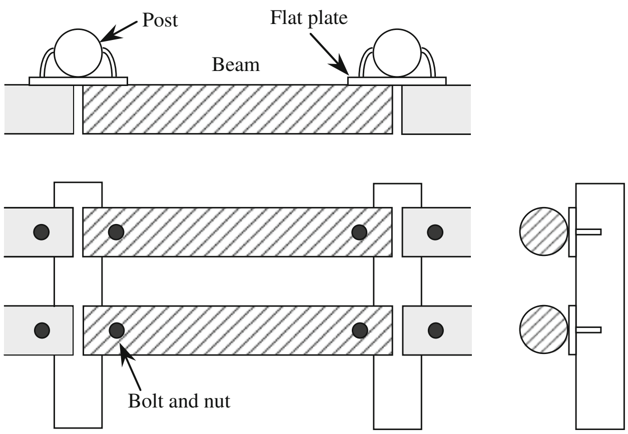


Fig. 1 Schematic diagram of a bar for timber guardrails

penetrates the plate and round bar. The bolt is held with a nut. Consequently the part where the bar contacts the plate is a line (Fig. 1). On the other hand, there are also other contacting examples between a bar and post: a rectangular bar is used or a round bar is placed on a half-round jig. In these cases, the area between a bar and jig is thought to be wide. Thus, an apparatus to increase the contact area was developed and flexural vibration tests were performed under various end conditions for rectangular and round bars of compact and actual-sizes.

Experiment

Specimens

Sugi (Japanese cedar, *Cryptomeria japonica* D. Don) was used for the specimens. Small rectangular bars with dimensions of 25 mm (radial, R) in width, 5 mm (tangential, T) thick and 300 mm (longitudinal, L) in length, small round bars of 25 mm in diameter and 250 mm in length, actual-size rectangular bars with dimensions of 45 mm (R) in width, 95 mm (T) thick and 1500 mm (L) in length and actual-size round bars of 180 mm in diameter and 2000 mm in length were made. In our previous work [3], the final resonance frequency after compressing specimens with the same dimensions of the small rectangular bar in this study was almost equal to the theoretical value for fixed ends.

The specimens were conditioned at 20°C and 65% relative humidity for several months and tests were performed under the same conditions.

Vibration test

To obtain the resonance frequency of the first mode by bending, flexural vibration tests were performed by the following procedure, with the apparatus shown in Fig. 2 used to realize various end conditions. The maximum loads applied to each end of the specimen were about 170, 400, 1000 and 2500 kgf for the small rectangular bar, the small round bar, the actual-size rectangular bar and the actual-size round bar, respectively.

An apparatus for realizing various end conditions (Takachiho Seiki Co., Ltd. KS-200) was used for the small specimens (Fig. 2a, b). For the rectangular bar, the span was 250 mm and both ends were supported by columns whose cross section was 25 × 25 mm of the apparatus. For the round bar, the span was 200 mm and both ends were supported by jigs installed on the columns of the apparatus. The contact length between the round bar and jig was 25 mm (Fig. 2d). Screwing a bolt attached to a load cell compressed the test specimen, whereupon the load was measured by the load cell and recorded by a data logger.

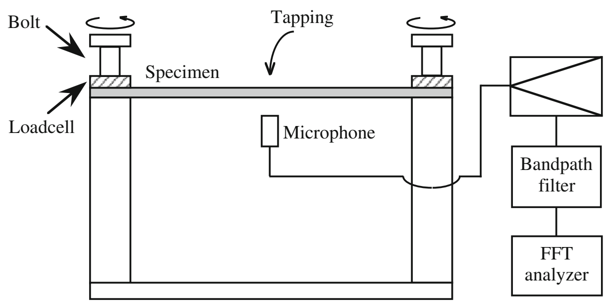
On the other hand, a tensile and compression testing machine (Minebea Co., Ltd. TCM-10000) was used for actual-size specimens (Fig. 2c). For the rectangular bar, the span was 1300 mm and both ends were supported by jigs whose area was 50 mm (L-direction of the bar) × 200 mm of the apparatus. For the round bar, the span was 1395 mm and both ends were supported by the jigs installed on the apparatus. The contact length between the round bar and jig was 105 mm (Fig. 2d). Two rubber sheets 5 mm thick were inserted between the round bar and each jig and the test specimen was compressed in the similar way as the four-point bending test.

The vibration was excited in the direction of compression at the center part by a hammer, with the bar motion detected by a microphone in the same place. The signal was processed through a fast Fourier transform (FFT) digital signal analyzer to yield high-resolution resonance frequencies.

A free–free flexural vibration test was also performed to measure the resonance frequency. A test specimen was suspended by two threads at the nodal positions of the free–free vibration corresponding to the first resonance mode with the vibration excited and recorded via the above-mentioned method. The resonance frequencies of the supported-sliding, supported ends and fixed ends conditions were estimated based on this frequency.

Results and discussion

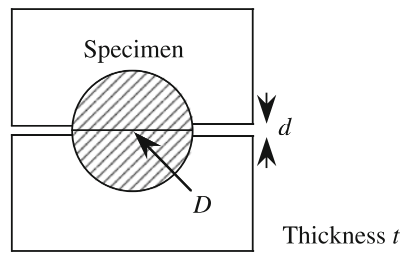
The measured resonance frequency rose rapidly early in the increasing compression load process and was nearly stable as in the previous study [3] (Fig. 3). It is thought that the significant increases in the resonance frequency for round bars were derived due to the area between the round bar and jig being wider than in the previous case [4].



a Schematic diagram of an apparatus realizing various end conditions for small specimens

b Apparatus realizing various end conditions for small specimens

c Tensile and compression testing machine realizing various conditions for actual-size specimens



(D, d, t)
=(25, 2, 25) for small round bars
=(200, 10, 105) for actual-size round bars
Unit: mm
Thickness: Contact length between round bar and jig

d Jig for round bars

Fig. 2 Schematic diagram of a vibration test under various end conditions

With a compression load of 0, the resonance frequency was between the values for the simply supported-sliding ends and simply supported ends. If the measured resonance frequency becomes stable for large compression stress, we can assume that the vibration of a test specimen in the compression direction is fixed sufficiently by the compression in this study. Since the resonance frequency increased slightly for large compression, the simply supported ends condition is thought to be imperfect and the end condition with the compression stress = 0 was between the simply supported-sliding ends and simply supported ends.

The ratios of maximum resonance frequency to the resonance frequency for the fixed ends (f_M/f_F) were 0.95, 0.82, 0.88 and 0.48 for the small rectangular bar, the small round bar, the actual-size rectangular bar and the actual-size round bar, respectively. For the rectangular bars, f_M/f_F for the actual-size specimen was lower than f_M/f_F for the small specimen. The span to thickness ratio (l/h) of the small specimen (250/5 = 50.0) was larger than l/h of the actual-size specimen (1300/95 = 13.7). For a thick bar, it will be difficult to restrict the shear deformation and rotation around a post perfectly; dividing a test specimen into many elements like simulation of a finite element method, the shear deformation and rotation of elements around the post will be insufficiently restricted. The length × thickness (the thickness direction is parallel to the compression load) plane of such an element will be shear-deformed and rotated easily during vibrating in a direction parallel to the compression load [3]. The fact that f_M/f_F for a small round bar with the span to diameter ratio (l/d) of 200/25 = 8.0 was lower than that for a small rectangular bar can be explained in the same way.

On the other hand, although l/d of the actual-size round bar (1395/180 = 7.8) was similar to l/d of the small round bar, f_M/f_F for the actual-size round bar was much lower than f_M/f_F for the small round bar. The apparatus for the small round bar was an all-in-one type, but the jig contacting the actual-size round bar did not combine the four-point bending apparatus perfectly, hence restricting

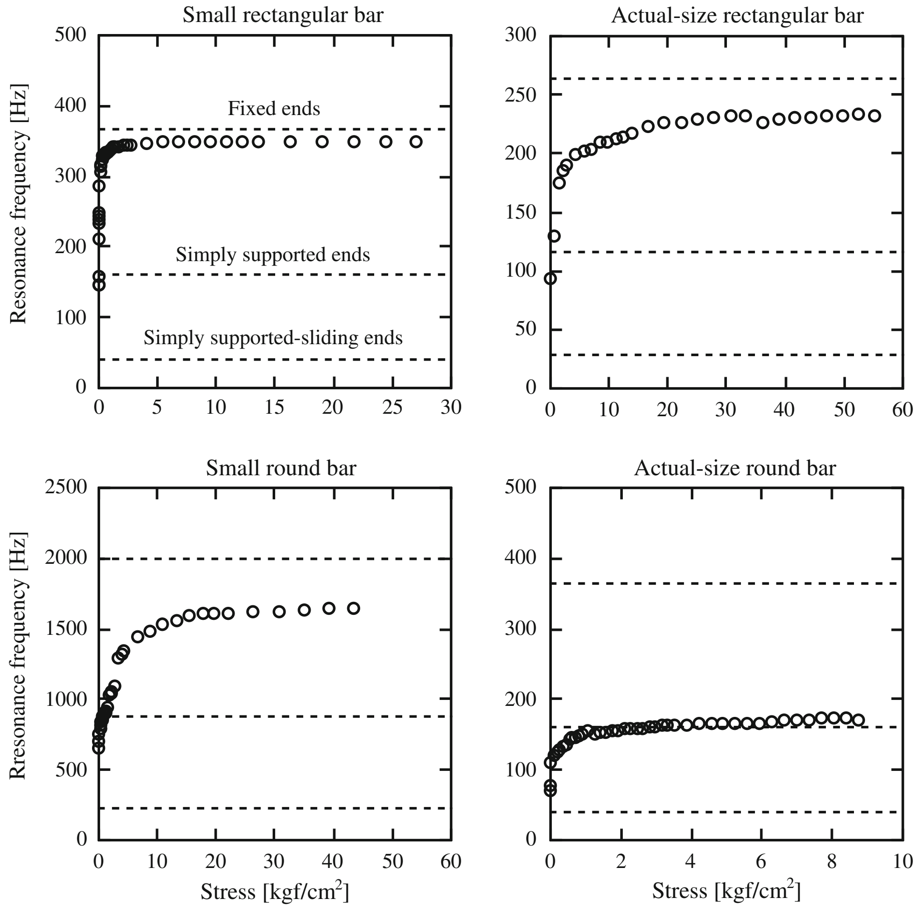


Fig. 3 Changes in resonance frequency with compression

rotation using the apparatus around posts might be difficult for the actual-size round bar.

Since compressing increased the resonance frequency about 2.5-fold, care should be taken when lumber is assembled into construction on-site. The resonance frequency of bars fixed to a post tightly or loosely must be respectively compared. If the change in the resonance frequency is small, no significant care will be needed. If the change in the resonance frequency is considerable, measuring with a bar fixed to a post tightly should be performed because the bars are fixed tightly to the post when inspecting wooden guardrails.

Conclusions

An apparatus to increase the contact area between bar and post for a wooden guardrails was developed and flexural vibration tests under various end conditions were performed for rectangular and round bars of small and actual sizes. Varying compression stress was applied to the parts around both ends of a test specimen and flexural vibration tests were performed with the following results:

1. The measured resonance frequency increased rapidly early in the increasing compression load process and was nearly stable for a large compression load.
2. The significant increases in resonance frequency for round bars are thought to be derived from the wide area between the round bar and jig.
3. When the compression load is 0, the resonance frequency was between the value for the simply supported-sliding ends and simply supported ends.
4. The value of f_M/f_F for the actual-size round bar was much lower than that for the small round bar, whereas the apparatus for the small round bar was the all-in-one type, but the jig contacting the actual-size round bar did not combine the four-point bending apparatus perfectly. Hence, restricting the rotation by the apparatus around posts might be difficult for the actual-size round bar.
5. The resonance frequencies of bars fixed to a post tightly and loosely must be respectively compared.

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