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SEISMIC BEHAVIOR OF FRAMES WITH UNEVEN LARGE SECTION BEAMS OF TRADITIONAL WOODEN STRUCTURE

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We report the progress of our research on understanding the seismic performance of frames with uneven large section beams and clarify the influence of the height of beams and the shape of fitting type joints on the behavior of the frame. In this study, we conducted a cyclic loading test for four test frames with spans of one or two and investigated the seismic performance and failure behavior. The major findings for the two-span frames are summarized as follows. (a) They caused fatal damage more readily than the one-span frames. The column that was caught in the even beams broke before other damage occurred. (b) Because of the asymmetry of the frame or the shape of the column-beam joints, the shear forces had directional dependence.

Keywords: Cyclic loading test, Seismic performance, Failure behavior, Shear force, Uneven beam, Limit-strength calculation.

1 INTRODUCTION

Numerous earthquakes have occurred in Japan. The 1995 Hyogoken-Nanbu Earthquake (M7.3) damaged many structures, and 90% of over 5,000 people suffered because of collapsed wooden houses. Subsequently, there have been many reports of wooden structures collapsing as a result of large earthquakes. Damage to traditional wooden structures often occurs around the joints. Therefore, it is essential to research the seismic resistance of joints.

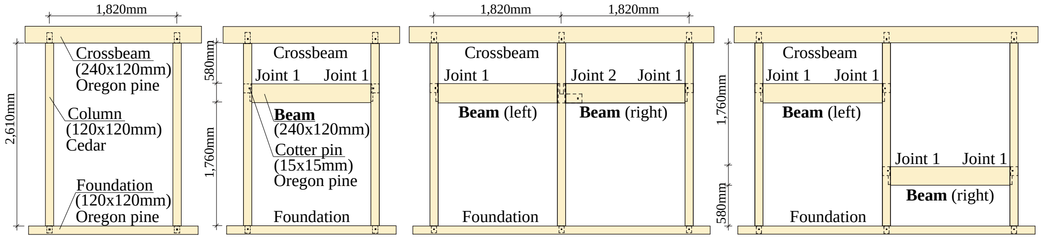
In a seismic evaluation method based on limit-strength calculation, a shear force having a one-to-one correspondence with a load-bearing element is defined, and the shear force of construction only adds the restoring forces of the element (Editorial 2008). However, there are various joint shapes and types of materials within a single load-bearing element, and the calculation method does not depend on these.

Therefore, we aimed to understand the seismic performance of the frames with uneven, large section beams and to study the influence of the beams on the behavior of the whole frame. We conducted a cyclic loading test on four test frames.

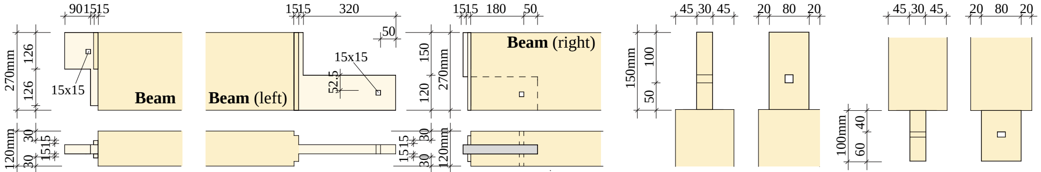
2 CYCLIC LOADING TEST

2.1 Specimens

We designed three specimens based on a typical traditional wooden frame (see Figure 1). Specimen F is the standard frame. Specimen S1 is a frame with a large section beam. Specimens S2 and S3 are two-span frames with beams. The uneven beams of Specimen 4 are exaggerated to verify whether they influence the seismic properties.



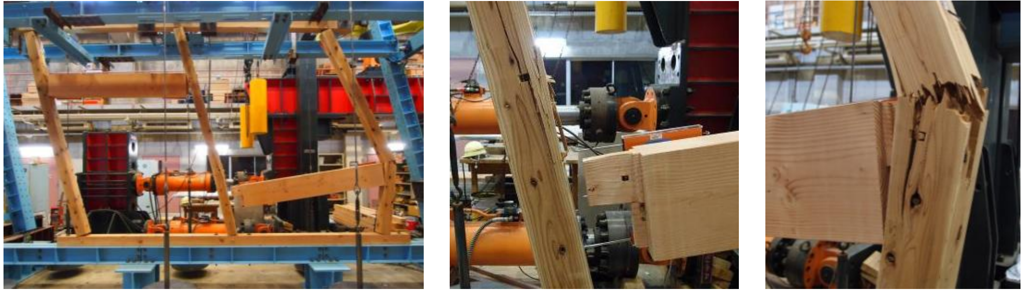
(a) Specimen F (b) Specimen S1 (c) Specimen S2 (d) Specimen S3



(e) Joint 1 (f) Fittiing of Joint 2 (g) Column capital (h) Column base

Figure 1. Details of specimens.

(a) S2, -1/8 rad (b) S2, -1/6 rad (c) S2, -1/6 rad (d) S2, +1/6 rad



(e) S3, +1/6 rad (f) S3, +1/6 rad (g) S3, +1/6 rad

Figure 2. Remarkable damage: (a) right-column splitting, (b) middle-column fracture and tenon failure parallel to grain, (c) right capital splitting, (d) left-column base fracture, (e) broken specimen, (f) middle-column splitting and beam tenon offset, (g) right-column fracture.

2.2 Loading Conditions

There was a surplus weight of $W = 9.8 \times 10^3$ (kN) on each column, apart from the dead load of the specimen (Nambu 2013).

The vertical displacement of the top of the specimen was measured by a displacement transducer. The rotation angle *R* was determined by trigonometry using the vertical displacement and the column length. Cyclic load was applied to the specimen such that the amplitude of *R* gradually increased. The shear force was calculated by subtracting the PΔ effect from the horizontal load measured by a load cell (Morii 2010). Strain gauges were attached to both faces of the member.

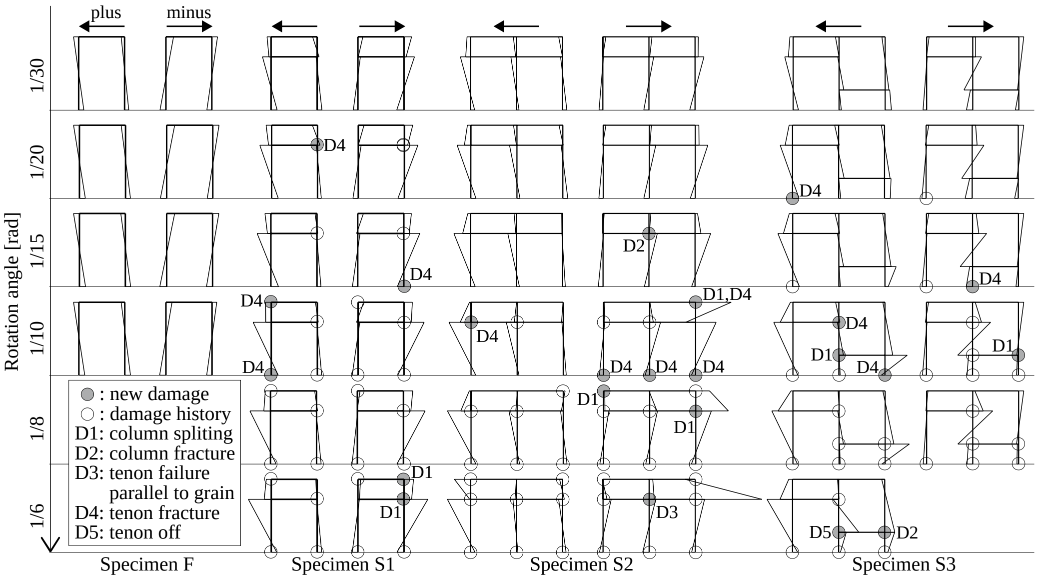


Figure 3. Bending moment and progress of damage (Architectural 2008).

3 TEST RESULTS

3.1 Main Damage

There was remarkable damage and bending moments were generated, as shown in Figures 2 and 3.

In Specimen F, conspicuous damage did not occur.

In Specimen S1, the right tenons of the beams were damaged at +1/20 rad. Additionally, the tenons of both column bases and the capital of the right column were broken before +1/10 rad. The right column split at the capital and column-beam joint at -1/6 rad.

In Specimen S2, the middle column was damaged at the column-beam joint at -1/15 rad. The left tenon of left beam was damaged at +1/10 rad. At -1/10 rad, the tenons of all the column bases were broken, and at the capital of the right column, the tenons were broken, and there was a column split. The capitals of the left and middle columns both split at the column-beam joint at -1/8 rad. The right tenon of the left beam was broken parallel to the grain at -1/6 rad.

In Specimen S3, the tenons of all column bases were damaged before 1/10 rad. The middle column split at the right-column beam joint, and the left tenons of the right beam were broken at +1/10 rad. There was a right-column split at the column-beam joint at -1/10 rad. The right column was broken at the column-beam joint, and the left tenon of the right beam was offset at +1/6 rad.

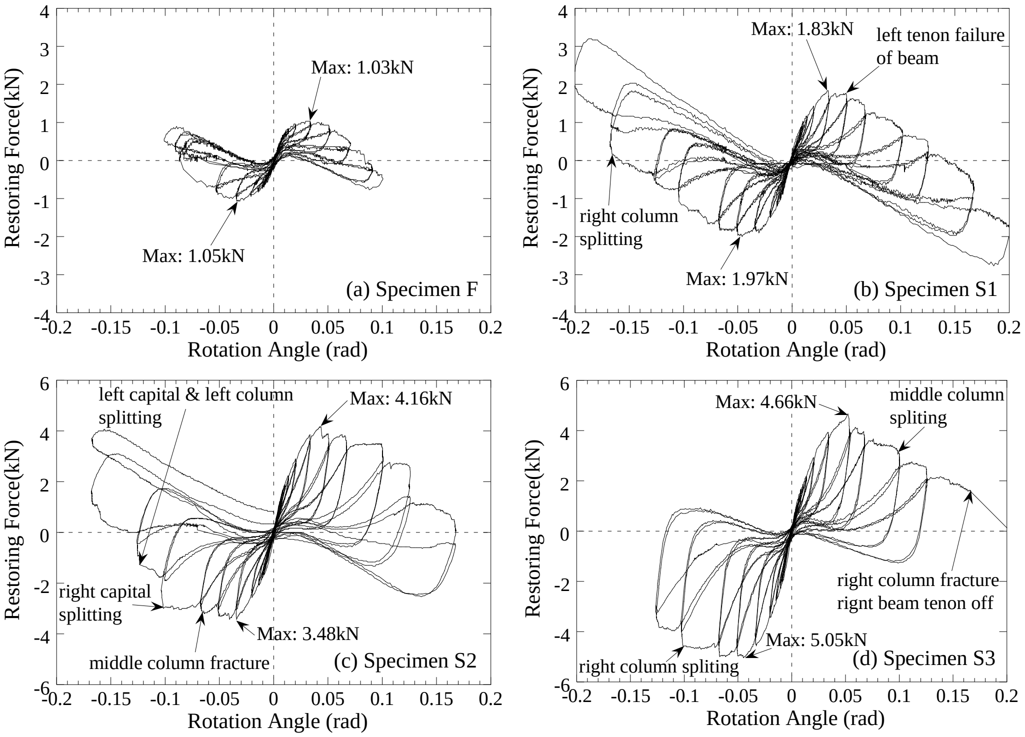


Figure 4. Restoring force.

3.2 Restoring Force and Shear Force

The restoring force and skeleton curves of the shear force are shown in Figures 4 and 5, respectively. Figure 5 compares the skeleton curves for both loading directions and the shear force with a “manual” limit-strength calculation.

For Specimen F and S1, the restoring force reached maximum values of 1.03 and 1.83 kN, respectively, at +1/30 rad. For both specimens, the shear forces in both loading directions were approximately the same as the manual value.

For Specimens S2 and S3, the restoring force reached maximum values of 4.16 and 4.66 kN, respectively, at +1/20 rad. These values are larger than the deformation of one span frame. For both specimens, the shear forces in both loading directions did not differ significantly from the manual value, but the shear forces had directional dependence. In Specimen S2, the frame was symmetrical, but the middle column-beam joint was not. On the other hand, in Specimen S3, the middle column-beam joint was symmetrical, but the frame was not.

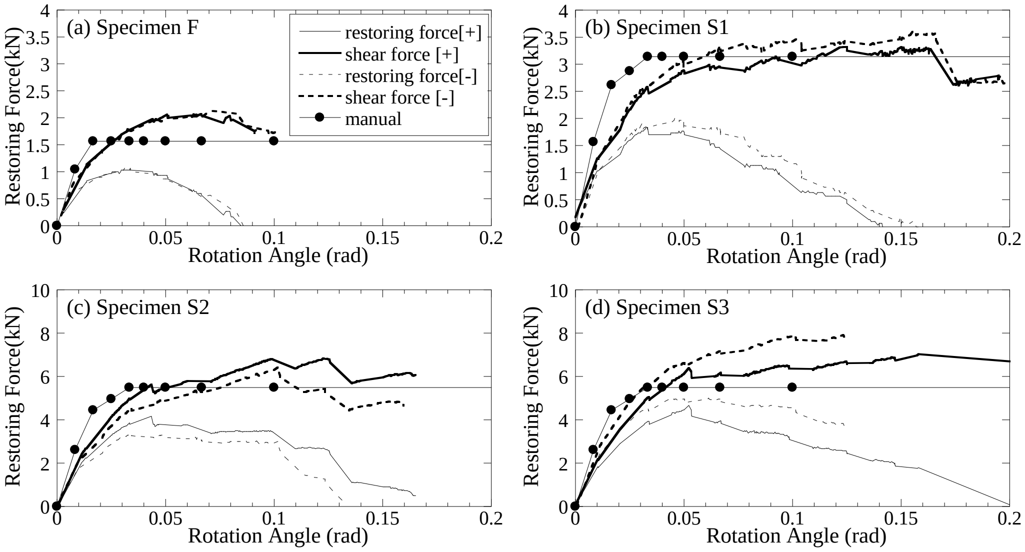


Figure 5. Skeleton curve of shear force.

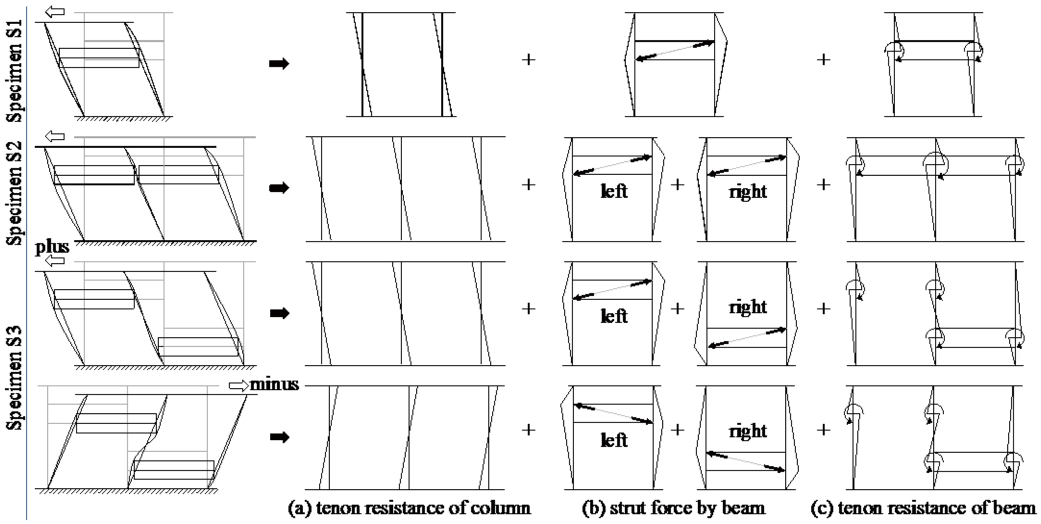


Figure 6. Mechanism causing shear force.

3.3 Findings

The two-span frame caused fatal damage—such as column splitting or column breaking—more readily and with smaller deformation than one-span frames. In particular, the column caught in the beams broke before other damage occurred.

The rotation angle of the two-span frame reached a larger maximum restoring force than that of the one-span frame. Because of the asymmetry of the frame or the shape of the middle column-beam joint, the shear forces had directional dependence.

Bending moments can be divided into three phenomena, as shown in Figure 6: the tenon resistance of a column, strut force by a beam, and tenon resistance of a beam (Matsumoto 2012). The leading column in the loading direction exhibited the largest bending moment.

3 CONCLUSIONS

We conducted a cyclic loading test on four frames with large section beams to understand the seismic performance of the frames and studied the influence of the beams on the behavior of the whole frame.

Our findings are summarized as follows:

(1) The two-span frame caused column splitting or column breaking more readily, and with smaller deformation, than the one span frame. In particular, the column caught in the beams broke before other damage occurred.

(2) In the two-span frame, because of the asymmetry of the frame or shape of the middle column-beam joint, the shear forces had directional dependence.

(3) The leading column in the loading direction exhibited the largest bending moment. Furthermore, for the frame with uneven beams, the bending moments and damage was complex.

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