Experiment on Structural Behavior of Metal Exterior Wall

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Abstract. In Japan, metal panels made from aluminum or steel are widely used as the exterior finishing for medium and low-rise buildings such as offices and commercial facilities. It is important to control the damage to the metal exterior wall in order to realize the continuous use of buildings after an earthquake.

In this study, a cyclic loading test of metal exterior wall of the scale of one metal panel was conducted. Test parameters are the material and the thickness of the panel. From the experiment, it was found that all specimens can be used without any significant damage up to a story drift angle of 0.01rad. In addition, experimental results indicate that the slip at the bolted joint causes the metal exterior wall to non-linearize, although the slip at screw joint does not greatly affect the overall behavior. Furthermore, it was confirmed that the metal exterior wall finally exhibited the ultimate strength due to the fracture at the edge of the screw joint.

Keywords: Metal panel · Exterior wall · Bolted joint · Deformation mechanism

1 Introduction

To prevent damage and falling of non-structural components during an earthquake is important in order to realize the continuous use of buildings. Especially for non-structural exterior walls, it is necessary to ensure sufficient capacity to follow to story drift of the structural frame. In Japan, metal panels made from aluminum, steel and so on are one of the exterior finishing that is widely used for medium and low-rise buildings. However, the seismic performance of metal exterior wall is not clear.

In this study, a cyclic loading test of metal exterior wall consisted of one metal panel and steel members (Fig. 1) was conducted. Since the metal exterior wall has various materials and shapes of its components, the specimen in this experiment is only an example. The significance of this research is to observe the deformation mechanism and ultimate state of the metal exterior wall.

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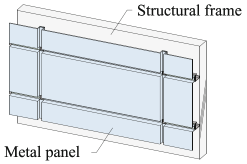

Fig. 1. Metal exterior wall

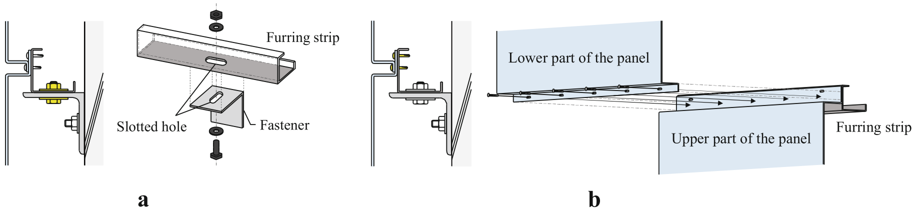

Fig. 2. a. Bolted joint. b. Screw joint

2 Construction of Metal Exterior Wall

The components of the metal exterior wall are metal panel and steel members called furring strip and fastener. The panel is formed by bending the metal plate with a thickness of about 0.8 mm to 5.0 mm into a box shape, and the height and width can be arbitrarily manufactured. One panel is supported at the upper and lower part by the furring strips. Fasteners are attached to each furring strip at regular intervals.

The joints of the metal exterior wall include a bolted joint between the fastener and furring strip (Fig. 2a) and a screw joint between the furring strip and the panel (Fig. 2b). For the bolted joint, the fastener has a slotted hole in the out-of-plane direction and similarly the furring strip has in-plane slotted holes to accommodate construction errors in the structural frame. In order to prevent the panel from slipping after construction, bolted joint is generally fixed by spot welding. However, in recent years, the non-welding method has been promoted due to fire risk [1]. The panel is fixed to the furring strip using drilling screws. Firstly, the upper part of the panel is fixed temporarily. Next, the lower part of the panel is overlapped with the panel of lower layer side and fixed together. The screw joint has slotted holes to cope with expansion and contraction due to thermal stress. Only the lower part of the panel where all screw joints are slotted holes can be moved in the in-plane direction.

3 Experiment Outline

3.1 Specimen

The specimen is a metal exterior wall for middle and low-rise buildings. The metal panel is a height of 838 mm and width of 1,800 mm (center panel, Fig. 3). In this experiment, four types of panel materials shown in Table 1 are utilized. In order to reproduce the actual screw joint, panels to be attached to the upper and lower part of the center panel are partially manufactured and jointed together. Figure 3 shows the dimensions of metal panels. These panels do not include the opening, the outside corner, and the inside corner.

Steel members for mounting the panels are two furring strips (Angle with lip: L-60 × 60 × 15 × 15 × 2.3) and four fasteners (Angle: L-90 × 90 × 7). The steel grade for general steel structure (SS400; F_y = 235 N/mm^2) is used. The dimensions of these steel members are shown in Fig. 4. Austenitic stainless-steel bolts with a nominal diameter of 12 mm (A2-70; F_y = 450 N/mm^2) and martensitic stainless steel drilling screws with a nominal diameter of 4 mm (C1-70; F_y = 410 N/mm^2) are used in this test.

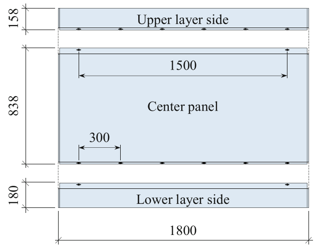

Fig. 3. Dimensions of metal panel

Table 1. Specimen list

Panel meterial	σ_u	t
	N/mm^2	mm
Pure aluminum: A1100P H14	120	2.5
Al-Mn series aluminum alloy: A3003P H24	140	2.5
Steel: SS400	400	2.3
Steel: SS400	400	0.8

σ_u: Nominal tensile strength
t: Panel thickness

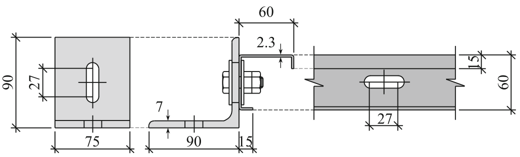

Fig. 4. Dimensions of fastener and furring strip

3.2 Setup

The overview of the setup is shown in Fig. 5. First, four fasteners are fixed to the reaction force jig. Then, two furring strips are attached horizontally and parallel to the fasteners. One furring strip is bolted to two fasteners. At this time, the bolts are tightened to 20kN, which is about 60% of the yield strength of M12 stainless steel bolt. After attaching the furring strips, the panels are fixed to them with drilling screws. The part shown in yellow in Fig. 5 (Roller jig) is a free roller in the horizontal direction. In the experiment, displacement is generated by hydraulic jacks connected to the left and right side of the roller jig via PC steel bars to reproduce the story drift.

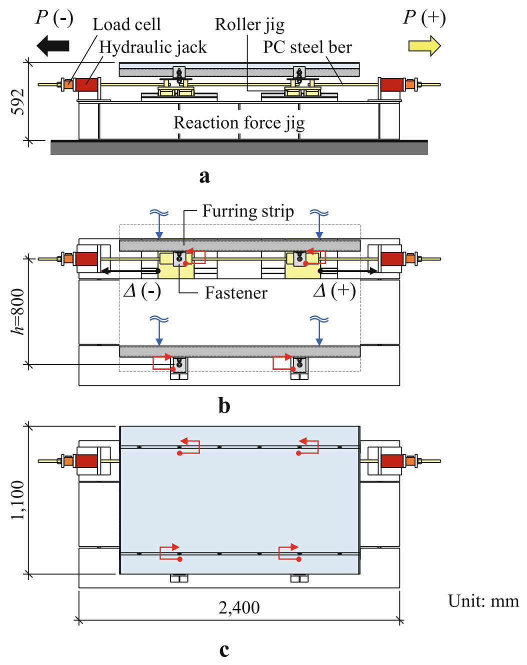

Fig. 5. a. Elevation view. b. Position of displacement transducer (1). c. Position of displacement transducer (2)

3.3 Measurement Plan

During the experiment, the in-plane load applied to the metal exterior wall (P) is measured by load cells connected to hydraulic jacks. Story drift ($\varDelta$) is the average value of the relative horizontal deformation between the left and right side of the roller jig and the reaction force jig. In addition, the story drift angle (R) is obtained by dividing $\varDelta$ by the distance between the upper and lower fasteners (h).

Furthermore, in this experiment, the measurement plan was formed on the assumption that the specimen would follow the story drift due to slippage at joints and rotational deformation of components. First, the slippage at joints is measured as the relative displacement at the bolted joints between the fastener and the furring strip, and at the screw joints between the furring strip and the panel.

The measurement position is shown in Fig. 5.b and Fig. 5.c. Adding the deformations of the upper- and lower-layer side, slippage at the bolted joint and slippage at the screw joint are obtained. These are divided by the distance between the upper and lower measurement points to convert them into deformation angles, and the sum of them is defined as the slippage at joints (R_j). The deformation angle obtained by subtracting R_j from the story drift angle R is defined as the rotational deformation (R_r). Rotational deformation consists of the rotational deformation of furring strip and other deformations such as bending panel and the bearing deformation at the screw joint along the height of the wall.

3.4 Loading

The loading history in this experiment is shown in Fig. 6. It is controlled by the amplitude of the story drift angle (R). Until $R = 0.01(1/100)$ rad, each cycle is performed for two cycles. Then each amplitude of 0.015(1/67) rad, 0.02(1/50) rad, and 0.03(1/33) rad, which are 1.5times, 2times, and 3times of 0.01rad, are performed for one cycle. The loading is continued until the specimen could not maintain its proof stress due to some kind of fracture.

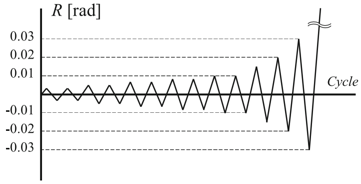

Fig. 6. Loading history

4 Experimental Result

4.1 Overall Behavior

Figure 7 shows the hysteresis curve obtained from the experiment. The vertical axis of the figure is the in-plane load applied to the metal exterior wall (P) and the horizontal axis is a story drift angle (R). Up to the story drift angle $R = 0.01$ (1/100) rad, there is a roughly linear relationship between the load and the story drift angle, indicating that the metal exterior wall almost elastically follows the deformation of the structural frame. Beyond $R = 0.01$rad on the other hand, the stiffness was reduced, and the residual deformation became remarkable. It was observed that the panel had cracks in some specimens. Eventually the edge of the screw hole fractured, and the load decreased rapidly (Fig. 8).

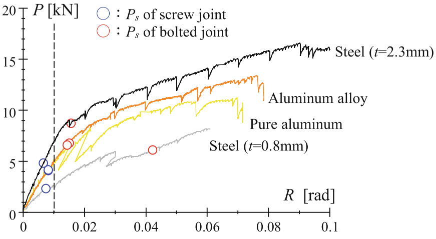

Fig. 7. Load-story drift angle relation

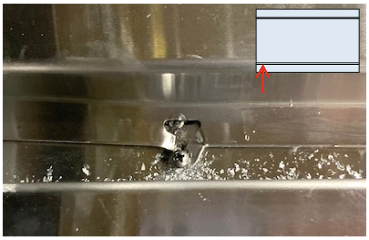

Fig. 8. Fracture at the edge of the screw hole

4.2 Deformation Mechanism

Figure 9 shows the percentage of the four components of deformation for each story drift angle. For all specimens, the rotational deformation accounts for a large percentage up to a story drift angle of 0.01rad, and after that the slip at joints increases.

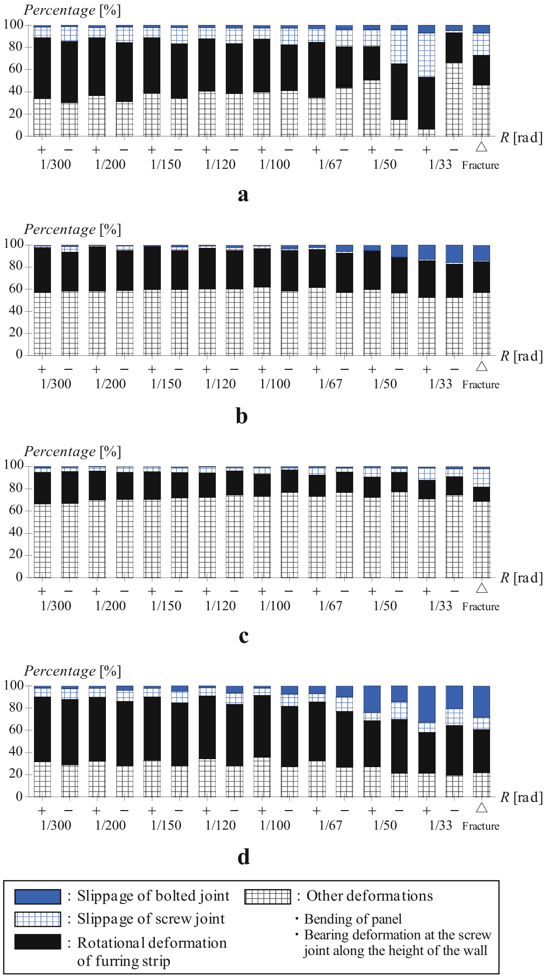

Fig. 9. a. Deformation mechanism (Pure aluminum, t = 2.5 mm). b. Deformation mechanism (Aluminum alloy, t = 2.5 mm). c. Deformation mechanism (Steel, t = 0.8 mm). d. Deformation mechanism (Steel, t = 2.3 mm)

Next, slip strength P_s of joint is evaluated. It is assumed that most of the initial stiffness of the hysteresis curve is due to the stiffness of the exterior wall components themselves. Thus, the evaluation range of the slip strength is defined as the point at which the 0.2 mm offset line from the initial stiffness intersects with the hysteresis curve (Fig. 10).

Slip strength of bolted joint is shown in red and that of screw joint is shown in blue, overlaying on the hysteresis curve of Fig. 7. The results indicate that the slip at the screw joint precedes the slip at the bolted joint, and that the slip at bolted joint causes the exterior wall non-linearize.

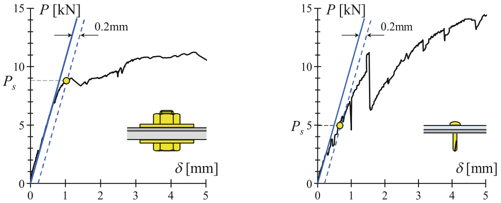

Fig. 10. Evaluation of slip strength of joints (in case of the specimen of aluminum alloy, left: bolted joint, right: screw joint)

4.3 Ultimate Strength

In this section, the ultimate strength of metal exterior wall is described. In the experiment, the fracture at the edge of screw hole was observed except for the specimen of steel of 2.3 mm. Then the in-plane load when the screw hole fractures is obtained as the ultimate strength.

Since the upper and lower screw joints are symmetrical, the bending moment $Ph/2$ (h: the distance between the screw joint along the height of the wall) due to the in-plane load acts on the screw joints on the lower layer side. As a result, a vertical reaction force corresponding to the bending moment works on each screw joint. Assuming that the specimen is in the total plastic state horizontally where all the screw joints reach the maximum strength, the reaction force acting on the side of the screw hole is calculated by Eq. (1).

$$R_m = \frac{P \cdot h}{2 \cdot \sum r_i} \tag{1}$$

where, r_i is the distance from the center of the screw group to the i-th screw position. On the other hand, when a fracture occurs at the lower part of the screw joint, if reference [2] is applied mutatis mutandis, the fracture strength can be obtained by Eq. (2) using the edge distance e and the screw hole diameter d shown in Fig. 11b.

$$R_m = \frac{P \cdot h}{2 \cdot \sum r_i} \tag{2}$$

where, σ_u is the lower limit of the standard tensile strength of the panel, and t is the panel thickness (Table 1). From Eq. (1) and Eq. (2), the ultimate strength of the metal exterior wall can be expressed by Eq. (3).

$$R_m = \frac{P \cdot h}{2 \cdot \sum r_i} \tag{3}$$

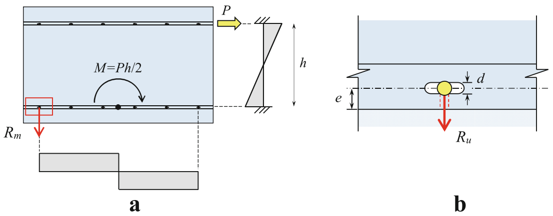

Fig. 11. a. Moment distribution. b. Screw joint

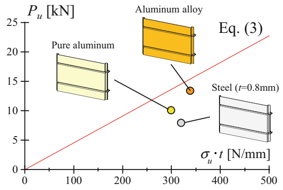

Fig. 12. Ultimate strength of metal exterior wall

Figure 12 shows a comparison between the calculated value and experimental value of the ultimate strength. The horizontal axis of the figure is the product of σ_u and t, which differs between the specimens. Although Eq. (3) is a little overestimated, it almost corresponds with the experimental results.

5 Conclusion

In this study, a cyclic loading test of metal exterior wall was conducted. The obtained findings are shown below.

1) The deformation of the metal exterior wall is realized by (i) slip at the bolted joint, (ii) slip at the screw joint, (iii) rotational deformation of the furring strip, and (iv) other deformations including bending of the panel, slip at the screw joint along the wall height and so on.
2) In the range where the specimen is elastic, (iii) rotational deformation of the furring strip and (iv) other deformations accounts for a large proportion in the overall deformation.
3) The ultimate strength of the metal exterior wall is determined by the damage to the screw joint.

References

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