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Mechanical Model of Gypsum Board Anchors Subjected Cyclic Shear Loading

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***Abstract*—**In this study, the mechanical model of various anchors embedded in gypsum board subjected cyclic shear loading were investigated. Shear tests for anchors embedded in 200 mm square size gypsum board were conducted to measure the load - load displacement curves. The strength of the gypsum board was changed for three conditions and 12 kinds of anchors were selected which were ordinary used for gypsum board anchoring. The loading conditions were a monotonous loading and a cyclic loading controlled by a servo-controlled hydraulic loading system to achieve accurate measurement. The fracture energy for each of the anchors was estimated by the analysis of consumed energy calculated by the load - load displacement curve. The effect of the strength of gypsum board and the types of anchors on the shear properties of gypsum board anchors was cleared. A numerical model to predict the load-unload curve of shear deformation of gypsum board anchors caused by such as the earthquake load was proposed and the validity on the model was proved.

***Keywords*—**Gypsum board, anchor, shear test, cyclic loading, load-unload curve.

I. INTRODUCTION

GYPSUM boards have been used as a substrate material for numerous buildings, with various interior fixtures being fitted to them. However, screws directly driven into gypsum boards are prone to fail by shear loading due to insufficient load-bearing capacity of the boards, making it difficult to safely secure such fixtures and devices to the boards. The use of gypsum board anchors (hereafter simply referred to as "anchors") is effective in securing such devices on the boards and complementing the load-bearing capacity. While anchors come in wide ranges of shapes and materials, few studies have compared their properties [1], with no quantitative indices having been provided for their selection. Authors were studied on the pull-out behavior of gypsum board anchors [2], [3].

This paper reports on a study in which shear tests were conducted on various types of anchors by monotonic and cyclic loading to investigate the characteristics of each type and proposes a method of estimating a unidirectional history curve, which is necessary for evaluating the load-bearing capacity under cyclic seismic loads.

II. OUTLINE OF EXPERIMENT

Fig. 1 shows the anchors used in the tests. The symbol JN represents a self-drilling screw type, JU, a self-drilling drive type, SO, a drilling insert type, and SN, a drilling screw type.

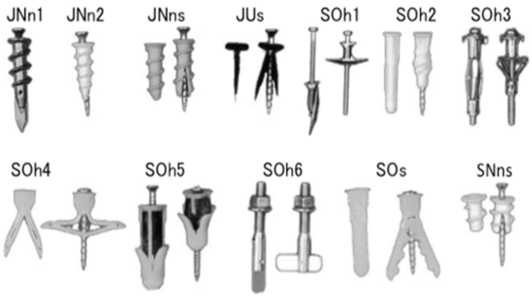

Fig. 1 Anchor bolts use in this study

The gypsum boards were regular gypsum boards 12.5 mm in thickness. An anchor was fixed to the center of each gypsum board 200 mm by 200 mm in size, which was fixed to a steel reaction board, and subjected to unidirectional cyclic shear displacement using a displacement-controlled fatigue testing machine shown in Figs. 2 and 3.

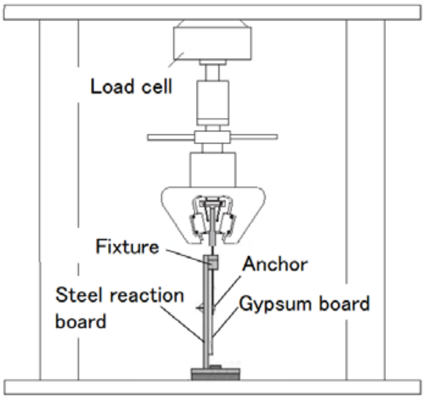

Fig. 2 Overview of shear test

The loading point displacement rate was 1 mm/min under repeating conditions, shown in Fig. 4, conforming to the test method specified in the standard test method for metal fastenings and fasteners "Test method of metal fastenings and fasteners for wood frame construction, Chapter 4" [4]. Monotonic loading tests were also conducted for comparison.

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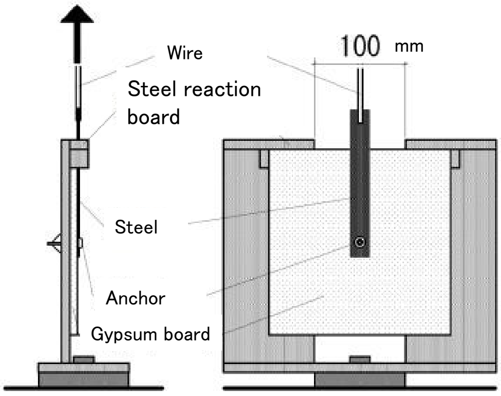

Fig. 3 Overview of shear loading

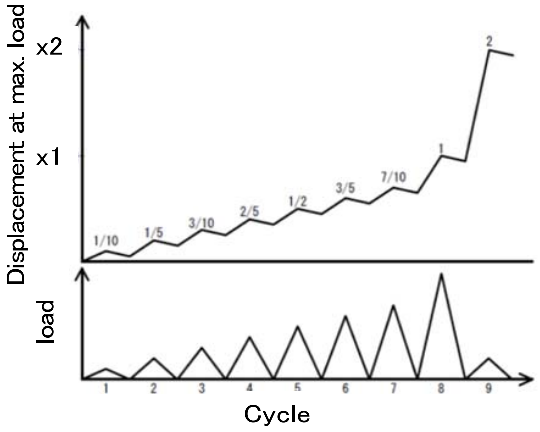

Fig. 4 Displacement repeating conditions

III. Estimation of Load-Unload Curves by Cyclic Loading Tests

Fig. 5 (a) shows a conceptual drawing of a load - displacement curve and unloading-reloading curves at arbitrary deformations and energy changes [5]. The unloading curves at C and D are linearly approximated to CA and DB. The elastic strain energy (Ue) at C and D is expressed as the area of ΔCAF and ΔDBE, respectively. The energy externally given to the specimen from C to D (dUw) is expressed as the area of □CFED, and the energy consumed for shear failure (dUf) is dUw – dUe. Therefore, dUf = □CFED – (ΔDBE - ΔCAF) = □CAED - ΔDBE =□CABD, which is the gray part of Fig. 5 (a). As to the accumulated change in the energy to the load point displacement, a, the energy given from the outside (Uw) is the sum of the energy consumed for shear failure (Uf) and the elastic strain energy (Ue). This relationship is illustrated as Fig. 5 (b). Fig. 5 (b) is determined by determining dUf, dUe, and dUw from the cyclic loading test results of each anchor. Ue is determined from P at an unloading point on the load-displacement curve, where estimation is desired, and the load point displacement, as in Fig. 5 (b). Linearly approximated unloading-reloading curves are then evaluated, and history curves under various cyclic tensile loads can be estimated (Fig. 6).

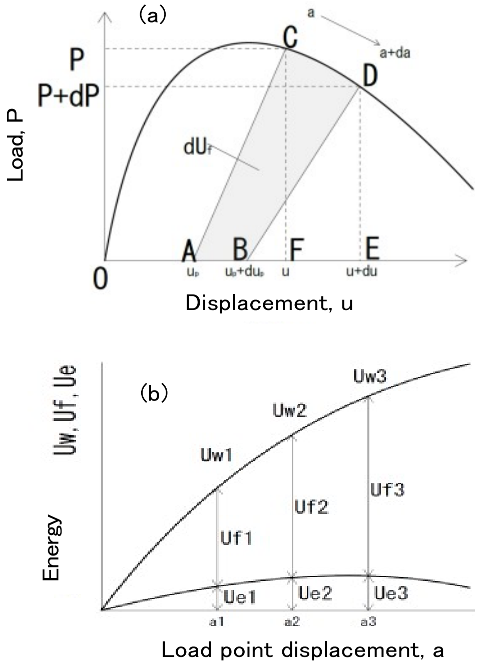

Fig. 5 Unloading-reloading curves and energy changes

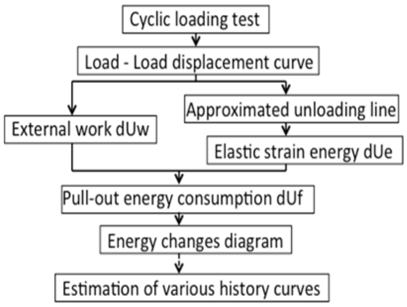

Fig. 6 Flowchart of estimating historic curves

IV. Test Results and Discussion

Fig 7 shows the test results. The shear properties widely vary depending on the anchor type.

A. Self-Drilling Anchors

Specimens JNn1 and JNn2, failure of the anchor was observed in the regular-hard gypsum board. JNns lead to a post-peak increase in the load at around a displacement of 5 mm, due to friction fixing by the expanded end. Also, reductions in the load are relatively slow. JUs lead to a small maximum load, with slow reductions after reaching the peak. Also, self-drilling anchors are characterized by the relatively small effect of the gypsum board type on the shear capacity.

B. Anchors Requiring a Pilot Hole

As to SOh1, failure of the gypsum board was observed. This led to rapid increases and reductions in the load, however attaining the large hear capacity. SOh2 shows a relatively small maximum load, with anchor failure in the regular-hard gypsum board; however, the load increases after the peak, as the gypsum board did not break. SOh3 shows a relatively small maximum load, with gypsum board failure. However, the load increases after the peak. SOh4 leads to gypsum board failure, but the reductions in the load are very slow, presumably due to the shape of the anchor after failure resembling the type of friction fixing by an expanded end. SOh5, which was made of a soft anchor material, shows increases in the load slower than the other anchors, but the post-peak reductions are rapid. The maximum loads of anchors that grip the board from behind other than SOh4 are very large when being placed into regular-hard gypsum boards. The increases and reductions in the load on SOs are both very slow. SNns shows a small maximum load, with the displacement to 0 kN being small. It was therefore confirmed that the load-displacement curves are clearly characterized by the methods of fixing.

C. Differences among Fixing Methods

Fig. 8 shows a conceptual drawing illustrating the differences in the shear resistance and characteristics among the fixing methods. JNn1, JNn2, JNns, Jus, SOh2, SNns showed #1 type and SOh1, SOh3, SOh4, SOh5, SOh6, SOs showed #2 type. Anchors fixed by screw friction show small maximum loads at pullout and subsequent slow reductions in proportion to the displacement. These anchors are mostly self-drilling, being impossible to drive into high strength gypsum boards. The type of gypsum board scarcely affected the shear capacity. Anchors fixed by friction of expanded ends show moderate curves of increases and reductions in the load, with the type of gypsum board slightly affecting the shear capacity. As to anchors that grip the board from behind, the effect of the gypsum board type was significantly observed on the shear capacity. These anchors are characterized by the rapid increases in the load to large maximum loads followed by rapid reductions with the failure of the gypsum board. The anchors that grip the board from behind also include specimens in which the anchor fractured, causing re-increases in the load after reductions. SOh6 is a characteristic example in which the expanded end re-resisted the shear forces after shear failure.

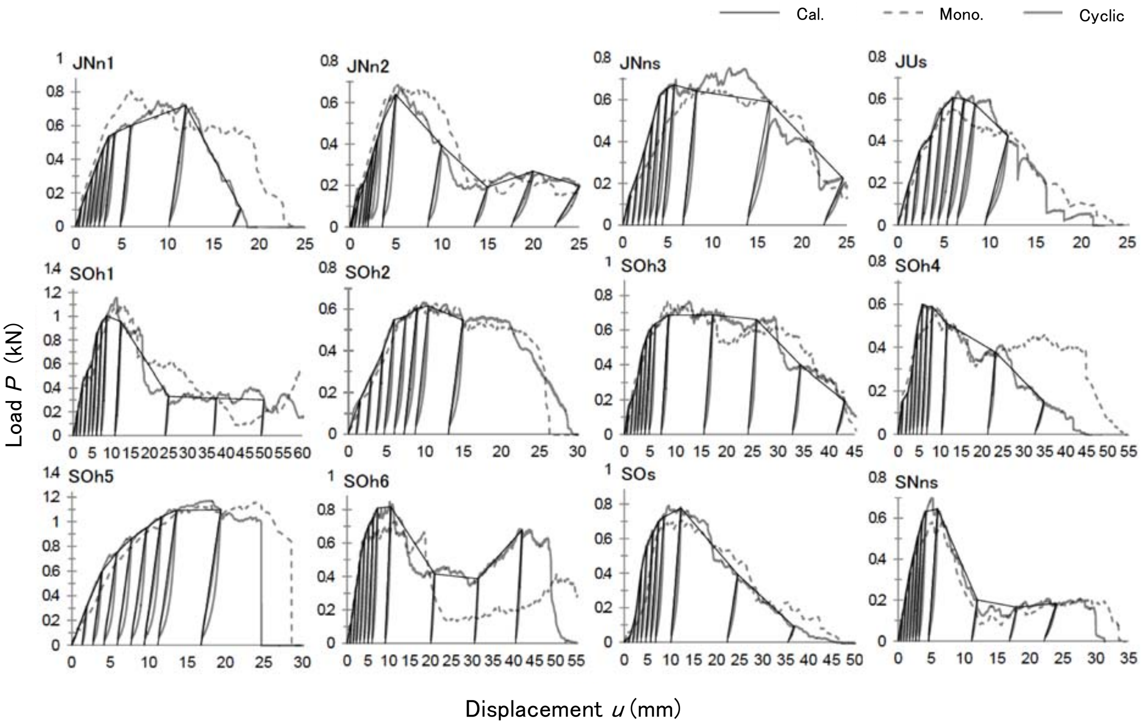

Fig. 7 Load – load displacement curves of various board anchors

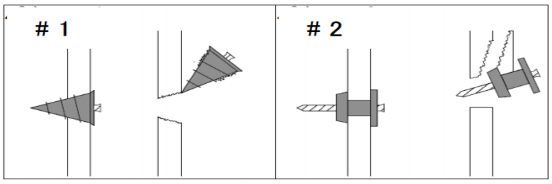

Fig. 8 Flowchart of estimating historic curves

D. Results of Cyclic Loading Tests

In Fig. 7, the load-displacement curves under cyclic tensile loads as well as those under monotonic loading were shown. The envelope curves of anchors under monotonic and cyclic loading nearly agree with each other. Fig. 9 shows the results of determining changes in the energy on the assumption that the unloading-reloading curves obtained from cyclic shear tests are straight lines. The unloading-reloading curve of each anchor assumed from the energy changes shown in Fig. 7, following the estimation flow shown in Fig. 6, is also superimposed in Fig. 7. The estimations nearly agree with the test results, proving the validity of the estimation method.

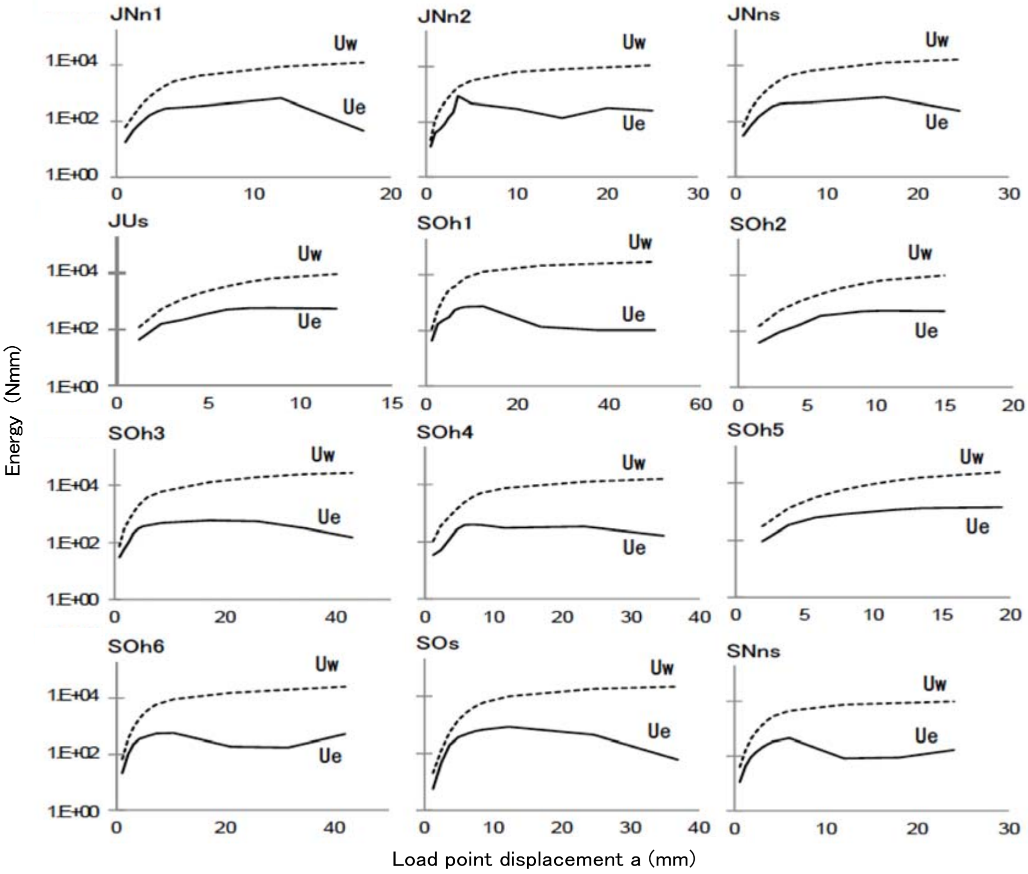

Fig. 9 Energy changes in shear test

V. CONCLUSIONS

Shear tests were conducted on various types of gypsum board anchors by applying monotonic and cyclic loads to grasp the characteristics of each type. Major conclusions of this study are as follows:

(1) Differences in the shear resistance and characteristics among the fixing methods of anchors were cleared.

(2) Anchors fixed by screw friction show small maximum loads at pullout and subsequent slow reductions in proportion to the displacement.

(3) Anchors fixed by friction of expanded ends show moderate curves of increases and reductions in the load.

(4) Anchors that grip the board from behind, these anchors are characterized by the rapid increases in the load to large maximum loads followed by rapid reductions with the failure of the gypsum board.

(5) Anchors that grip the board from behind also include specimens in which the anchor fractured, causing re-increases in the load after reductions.

(6) A method of estimating unidirectional unloading-reloading curves under cyclic loads, such as seismic loads was proposed and the results of estimation by the proposed method agreed with the test results, verifying the validity of the estimation method.

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