NEW DYNAMIC TESTING METHOD ON BRACED-FRAME SUBASSEMBLIES WITH STEPPING COLUMNS

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ABSTRACT

Earthquake resisting frame systems with stepping columns have been developed in the US and Japan. The key components of the system are rigid braced-frames, vertical post-tensioning strands, and replaceable dampers. Uplift behaviors of base-column depend on vertical forces such as the self-weight, the live load, and the post-tensioning. Total weight of a building is supported by earthquake-resisting components and leaning-columns (gravity-columns). Therefore, in order to realize uplift behavior of columns in small residential buildings by conducting experiments, earthquake-resisting components have to support actual weight. In addition to this, vibration characteristic of test specimens can be realized by the addition of inertial mass supported by leaning-columns. In this paper, new dynamic test method to realize uplift behavior of earthquake resisting frame system has been developed. At the present stage, dynamic tests on single earthquake resisting component can be realized by using this system. A weight related to uplift behavior is supported by small columns placed on shoulders of test specimen. Test-system composing inertial mass which adjusts vibration characteristic of test specimen is supported by gravity-columns pinned at the both ends. Vertical sliders connect small columns and test-system, and inertial force at the weight related to uplift behavior can be moved to test-system through these sliders. Therefore, inertial forces of total mass can be gathered to test-system, and test specimen can be loaded by the loading-fork allowing uplift behavior.

INTRODUCTION

In the Northridge and Kobe earthquakes, some buildings lost structural functions, although many buildings avoided collapse as to save human life. The loss caused the termination of social and industrial activities, and severe economic loss. At the stage of seismic design, it is important to consider restoring structures immediately after an earthquake. As stated in the Uniform Building Code, "The purpose of the earthquake provisions herein is primarily to safeguard against major structural failures and loss of life, not to limit damage ore maintain function (ICBO 1997)". Also in Japan, a heavy earthquake country, the differences of a thought concerning actual seismic performances between the people and structural engineers have been pointed out after the Kobe earthquake. New technology which realizes not only seismic resistances (strength, stiffness, and plastic rotation capacity) but also protecting their functions will be immediately needed.

On the other hand, it has been observed that some building structures with uplifting of foundation have been no-damaged in structural functions after the past earthquakes. Analytical study on damage-decrease due to uplifting had been carried out (Hayashi 1996). RC and steel structures with base-column or foundation allowed to uplift (stepping column) have been developed in the US and Japan (Huckelbridge et al. 1977; Midorikawa et al. 2002; Iwashita et al.

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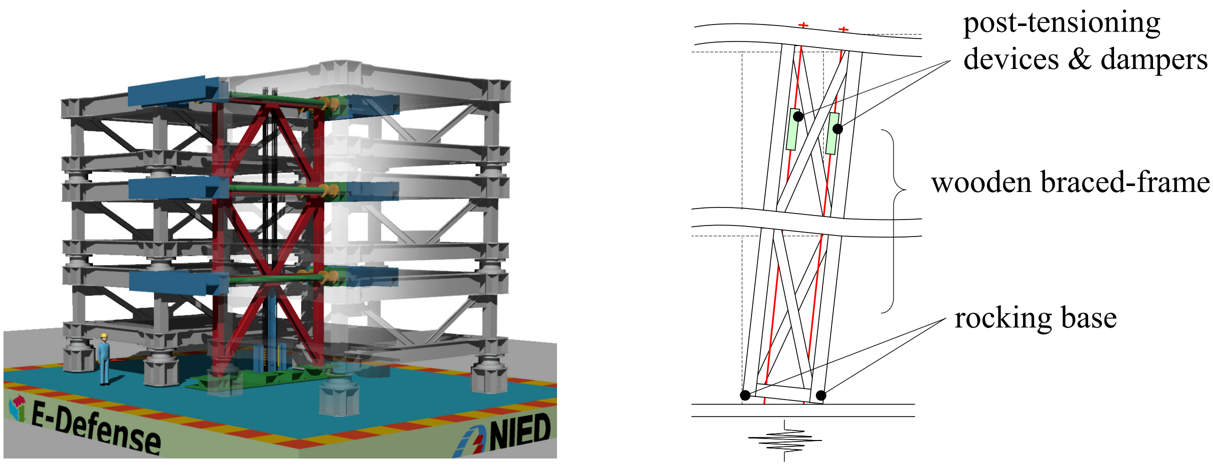
2003). And then, some technologies have been applied to actual structures (Kasai et al. 2001; Buckle 2002).

Recently, controlled rocking frame composed of rigid braced frames, vertical post-tensioning strands, and replaceable dampers has been proposed (Deierlein and Hajjar et al. 2005). The controlled rocking system shown in Fig. 1(a)., a large (2/3) scale three-story frame has been tested at the E-Defense facility in August 2009 (Deierlein et al. 2009). In addition to demonstrating the reliability of the system and its components, this test has been an important proof-of-concept of the design criteria, constructability, and performance of the system. The test is jointly planned with collaborators from Stanford University (Gregory G. Deierlein and H. Krawinkler), University of Illinois (J. Hajjar), Tokyo Institute of Technology (T. Takeuchi, K. Kasai and S. Kishiki), Hokkaido University (M. Midorikawa), and E-Defense (M. Nakashima and T. Hikino). And also in Japan, controlled rocking "wooden wall" composed of similar components has been proposed by the authors (Kishiki and Wada 2009), and shown in Fig.1(b). The authors focused on damage distribution of rocking rigid-wall (braced frame). Rocking rigid-wall forces the other earthquake-resisting components to work following the 1st mode-shape which is led to same story drift at every floor. Therefore, brittle shear failures of old wooden and RC walls are avoided by damage-distribution of rocking rigid-wall. Retrofit projects using damage-distribution of rocking controlled wall are in progress (Wada et al. 2009).

Major experimental research projects on rocking controlled frames have been carried out using a large scale test specimen. To further examine dynamic behavior, large shaking tables such as the E-Defense shaking table facility have been used. Since the cost of such a specimen can be very high, testing a part of the specimen such as the plane frame of a building would be much more economical and would still yield meaningful data. Such test methods would also enable parametric studies requiring multiple specimens. Accordingly, a so-called "test-bed" having a multipurpose inertial mass system (Takeuchi, Kasai, et al. 2007, 2008) is currently constructed. This test bed will be utilized for the aforementioned study on innovative methods,



(a) (b)

Fig. 1. Recent project of rocking controlled frame. (a) a large scale three-story frame tested ate the E-Defense facility (Deierlein et all. 2009), (b) rocking controlled "wooden wall" (Kishiki and Wada et al. 2009)

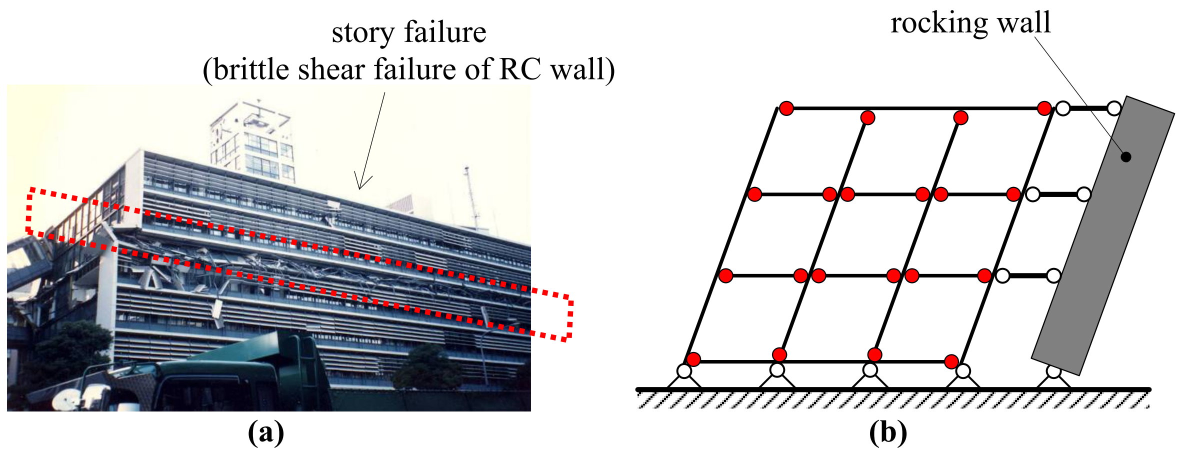


Fig. 2. (a) Story failure of the City Hall of Kobe, (b) design concept of retrofit project using rocking wall (Wada et al. 2009)

involving researchers from both the US and Japan, as part of the NEES/E-Defense Collaboration Research Program. However, at the early stage of developing new system, a single innovative component should be tested in laboratory of university. In this paper, new dynamic testing method on rocking controlled braced-frame subassemblies has been proposed. Uplift behaviors of base-column depend on vertical forces such as the self-weight, the live load, and post-tensioning. Total weight of a building is supported by earthquake-resisting components and leaning-columns (gravity-columns) as shown in Fig. 3. Therefore, in order to realize uplift behavior of columns in small residential buildings by conducting experiments, earthquake-resisting components have to support actual weight. In addition to this, vibration characteristic of test specimens can be realized by the addition of inertial mass supported by gravity-columns. To further examine dynamic behavior of a single rocking controlled wall and conduct parametric studies, new dynamic testing method has to be immediately developed.

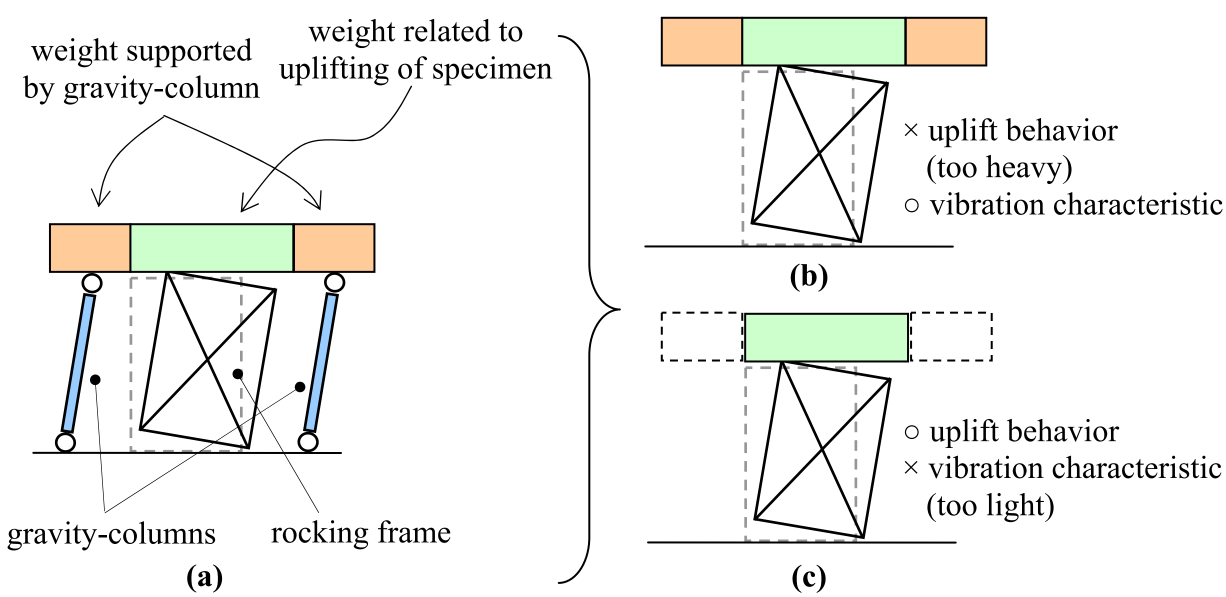


Fig. 3. the reason why additional weight and gravity-columns are needed (a) actual condition of rocking system, (b) conventional test method 1, (c) test method 2

NEW DYNAMIC TESTING METHOD

Mentioned above, uplift behaviors of base-column depend on vertical forces such as the self-weight, the live load, and post-tensioning. Total weight of a building is supported by rocking controlled frame components and gravity-columns. Therefore, in order to examine dynamic behavior with uplifting of base-columns in small residential buildings by dynamic experiments, rocking controlled frame has to support actual weight. In addition to this, vibration characteristic of test specimens can be realized by the addition of inertial mass supported by gravity-columns. The proposed testing system is illustrated in Fig. 4. With capacity limitations of testing equipment, testing system accommodating a one-story single rocking controlled frame has been constructed in our laboratory. Having larger capacity limitations of the testing equipment, the proposed test arrangement can accommodate multi-story structural models. A weight related to uplifting of test specimen and additional weight (so-called seismic weight or inertial mass) are placed on upper frame. This upper frame and additional weight are supported by four gravity-columns pin-connected at the both ends. Test specimen is installed between four gravity-columns, and supports weight related to uplifting through vertical linear-sliders. The upper frame is connected to test specimen by loading-system, and inertial force of total weight are transferred to test specimen through the loading-system.

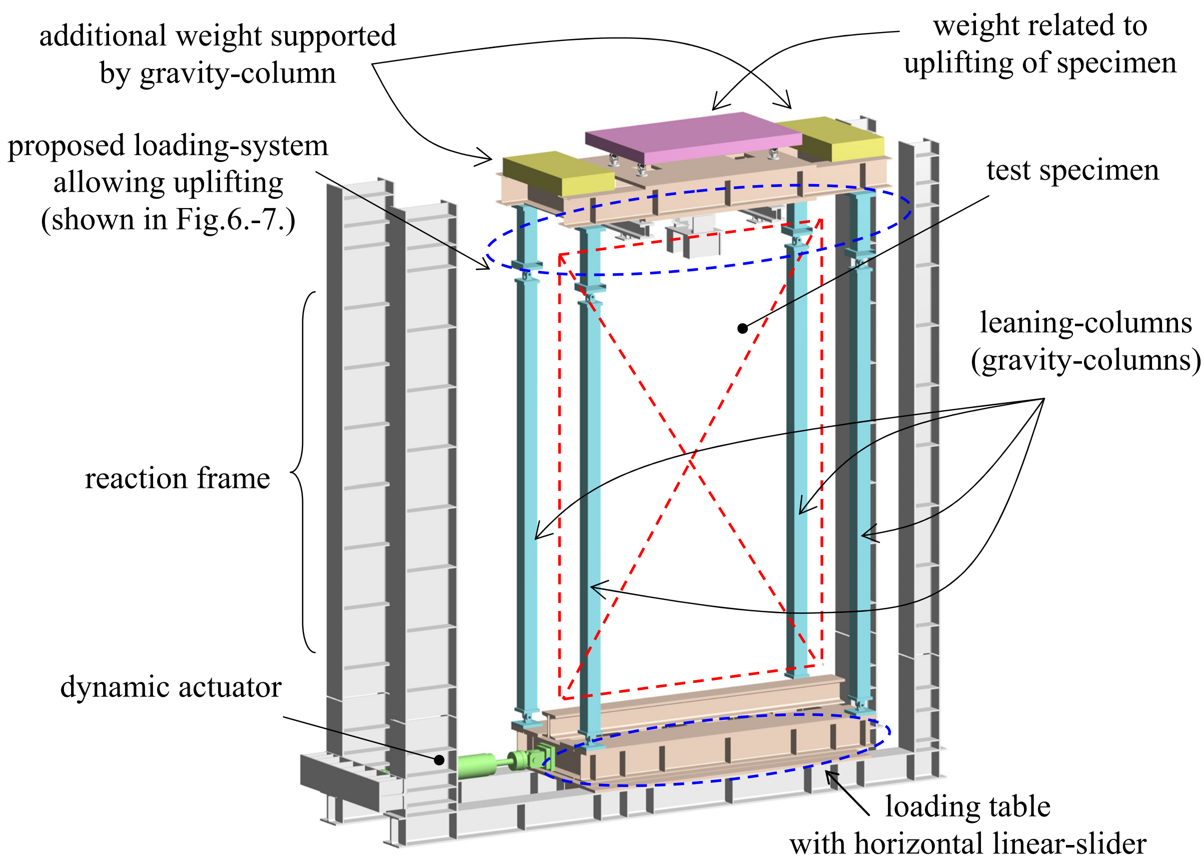


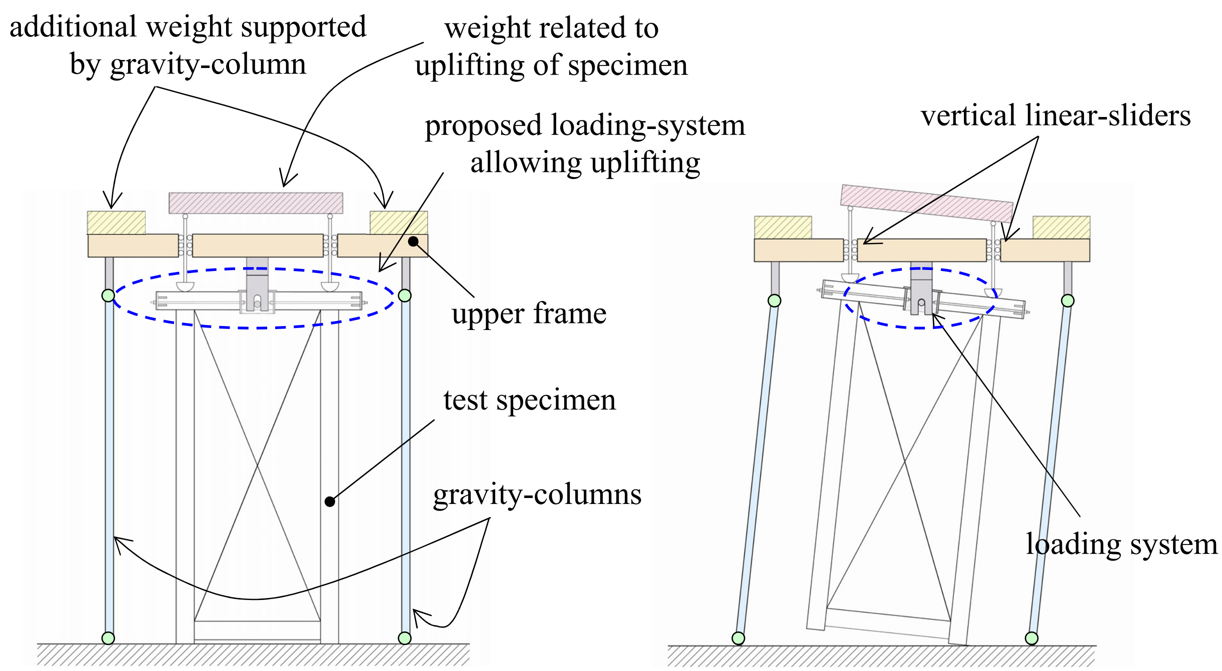
Fig. 4. Proposed test setup for a single rocking controlled wall.

Behavior of rocking controlled system in the proposed test setup is illustrated in Fig. 5. The gravity-columns hardly resist lateral force, although they support additional weight. Additional weight works as inertial mass system, and brings P-Δ effects to the test specimen. In addition to this, to further examine quasi-static behavior of a single rocking controlled frame, these experimental studies are realized by connecting the upper frame to reaction frames.

Details of System Supporting Weight related to Uplifting

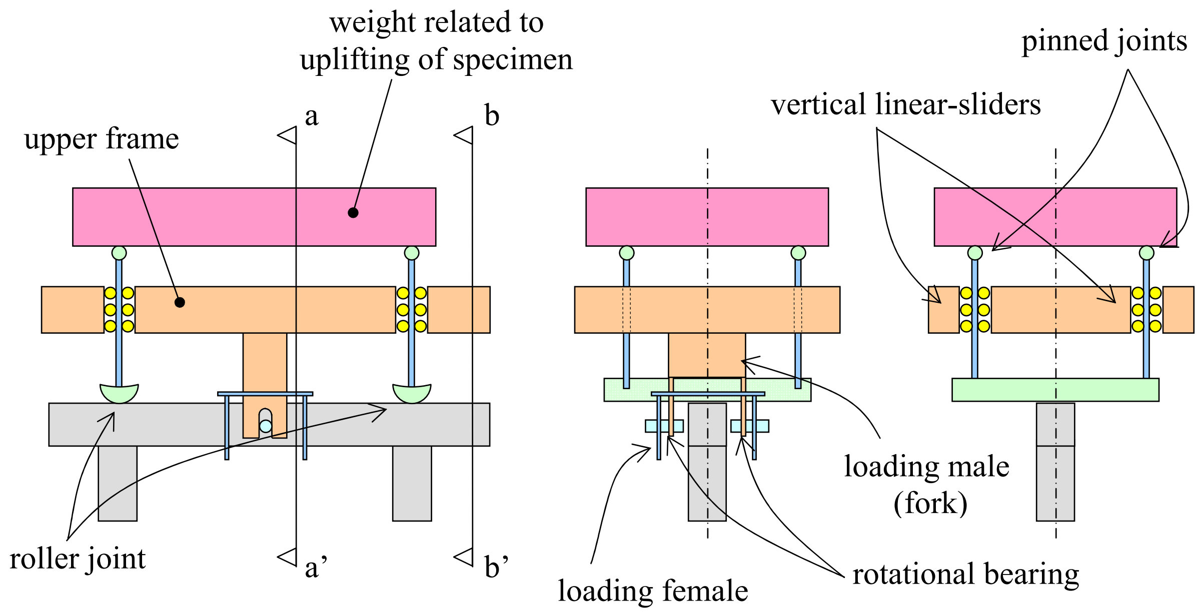
Test specimen supports the weight related to uplifting through four vertical linear-sliders. Details of system supporting weight related to uplifting are illustrated in Fig. 6. The four vertical linear-sliders are composed of two pairs, and each pair is placed on shoulders (point of beam-column-joint) of test specimen, respectively. At the top side, these sliders are pin-connected to the weight. On the other hand, these sliders have a semicircular shape, and are roller-connected to test specimen at the bottom side. Therefore, test specimen is able to rock when overturning moment reaches to limitation decided by the weight and post-tensioning force.

Inertial force of the weight related to uplifting is transferred to upper frame through the vertical linear-sliders. The upper frame is composed of wide-flange section, the sliders are able to transfer inertial force by moment-resisting caused between top- and bottom- flange connections. An additional weight is directly transferred to upper frame. And then, inertial force of the total weight is moved from the upper frame to the loading system (loading fork).



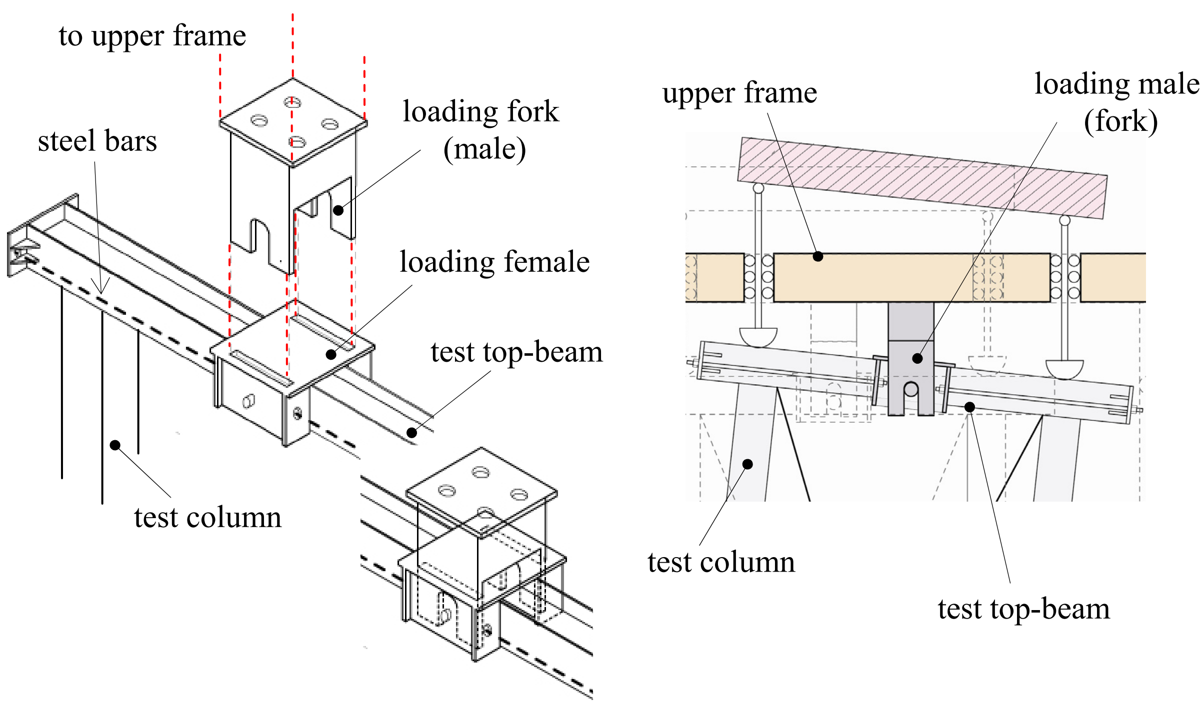
(a) **(b)**

Fig. 5. Behavior of rocking controlled system in the proposed test setup. (a) elevation of test setup, (b) rocking behavior of test specimen



(a) (b) (c)

Fig. 6. Detail of joint between upper frame and test specimen. (a) elevation, (b) a-a' section, (c) b-b' section



(a) (b)

Fig. 7. Detail of loading-system at the top-beam of test specimens

Detail of Loading-System at the Top-Beam of Test Specimens

Proposed loading-system which transfers inertial force of the total weight to test specimen is composed of male and female components. Detail of the system is illustrated in Fig. 7. The female part is placed on top-beam of test specimen with small friction. The male part has a fork shape, and the fork is contacted to rotational bearings of the female part. And then, four steel bars connect the female part to edge of top-beam of the test specimen. Therefore, the loading-system allows test specimen to rock with transferring of inertial force of the total weight.

CONCLUSIONS

In Japan, a heavy earthquake country, the differences of a thought concerning actual seismic performances between the people and structural engineers have been pointed out after the Kobe earthquake. New technology which realizes not only seismic resistances (strength, stiffness, and plastic rotation capacity) but also protecting their functions will be immediately needed.

It has been observed that some building structures with uplifting of foundation have been no-damaged in structural functions after the past earthquakes. Rocking rigid-wall forces the other earthquake-resisting components to work following the 1st mode-shape which is led to same story drift at every floor. Therefore, brittle shear failures of old wooden and RC walls are avoided by the damage-distribution of rocking rigid-wall. Retrofit projects using damage-distribution of rocking controlled wall have been proposed.

At the early stage of developing new system, a single innovative component should be tested in laboratory of university. Uplift behaviors of base-column depend on vertical forces such as the self-weight, the live load, and post-tensioning. Total weight of a building is supported by earthquake-resisting components and gravity-columns. Therefore, in order to realize uplift behavior of columns in small residential buildings by conducting experiments, earthquake-resisting components have to support actual weight. In addition to this, vibration characteristic of test specimens can be realized by the addition of inertial mass supported by gravity-columns. In this paper, new dynamic testing method on rocking controlled braced-frame subassemblies has been proposed.

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