International Journal of Advance Research in Science and Engineering
Vol. No.5, Issue No. 04, April 2016
www.ijarse.com
IJARSE
ISSN 2319 - 8354

EMPIRICAL STUDY AND KNOWLEDGE ACQUISITION ON DESIGN OF COMPOSITE STEEL AND CONCRETE FRAME FOR TALL BUILDINGS

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ABSTRACT

This paper presents an advanced structural framing system, which can construct cost-efficient high-rise buildings with high additional value. Main components are comprised of

(1) Earthquake-resisting core walls with boundary beams, which can bear almost all of the earthquake forces,

(2) Outer frames and

(3) The inversed haunch beams of office areas released from earthquake force. These characteristics give flexibility to building planning and future possible renovations. The seismic response analysis results illustrated that the earthquake-resistance standards of Japan, as a severely seismic country, could be satisfied, and the boundary beams reduced the seismic response. The loading tests confirmed that the shear strength and bending characteristics of the earthquake-resisting walls with built-in steel could be evaluated by conventional design equations for reinforced concrete earthquake-resisting walls. It was also verified that the boundary beams proposed had a large equivalent damping factor and could decrease damage compared with boundary beams of normal cross-sections.

Keywords: Hybrid wall system, Embedded steel frames, Analysis and tests, Anti-seismic for intensity 8.

I. INTRODUCTION

Sustainability of current and future tall buildings has become an important issue in terms of improving asset value and contributing to future society. Some methods of accomplishing sustainability are separation of the skeleton and infill, and integration of earthquake-resisting elements into building structures. Earthquake-resisting element integration, for example earthquake-resisting walls in the core and also tubular outer structure, has already been done. However, these methods alone are insufficient to ensure safety against large earthquakes in severe seismic countries like Japan. Furthermore, it is expensive to separate earthquake-resisting members and permanent load support members. The authors propose an advanced structural framing system for constructing highly value-added

high rise office buildings at low cost. Main components of the proposed structural framing system are comprised of, earthquake-resisting core walls, which can bear almost all of the earthquake forces and outer frames. The core walls are connected to each other by boundary beams working as dampers. These structural components release the floor framing of office areas from earthquake force; thus, it can be supported by simpler structural components, e.g. inversed haunch beams. These characteristics give flexibility to building planning and future possible renovations. Exactly, its system creates a tower building with multi-function by hybrid structure. (Here in after called HMT for short) It is noted that HMT can be applied to hybrid buildings such as those where the upper stories are a hotel, etc.

In this paper, we report the composition of the HMT and, seismic response analysis results for a model building. Then, the loading test results of the earthquake resisting core walls with built-in steel and the boundary beams for the purpose of realizing the HMT are illustrated.

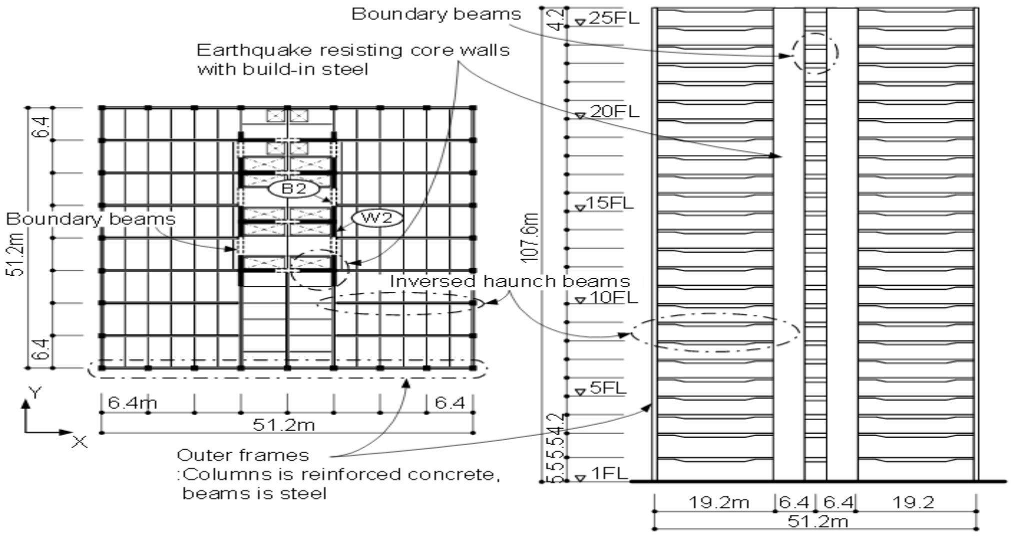


Figure 1. HMT's composition and subject building

Accordingly, HMT creates the merits of both planning and facility equipment as follows:

(1) Three-dimensional free space: HMT realizes office space that ensures plane and vertical variability. Because changes can be made to meet future business requirements, the asset value of the building is improved. For example, it becomes feasible to maintain tenant-dedicated elevators and stairs, halls using the two-story space and free layout of well space (see Figure 2).

(2) Free module: The efficient core planning can be created, since the core module is separated from the main module. Therefore the ratio of the office area to the total area can be augmented. For example, a compact planning can be efficiently made by setting the main module span to 7.2m and the core module span to 6.4m to match the elevator module.

(3) Free mechanical space: The inversed haunch beams can create flexibility of ducting works. Therefore the equipment space of the air conditional systems is reduced by 25% compared to the concrete filled steel tube structure. For example, in the conventional structure, if a duct is threaded through a beam, it has to be divided due to the constraint of the opening area. If HMT is employed, the ducting can freely pass under the beam, thus enabling efficient duct laying while maintaining a larger area (see Figure 3)

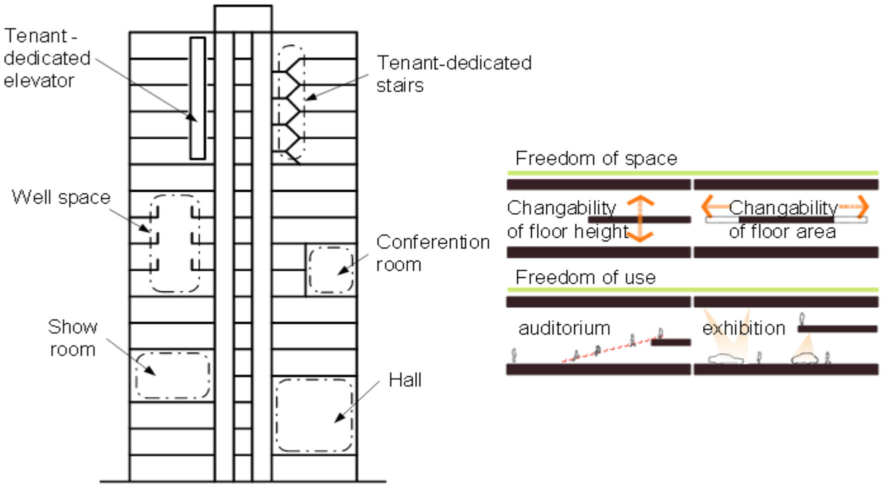


Figure 2. Three-dimensional free space

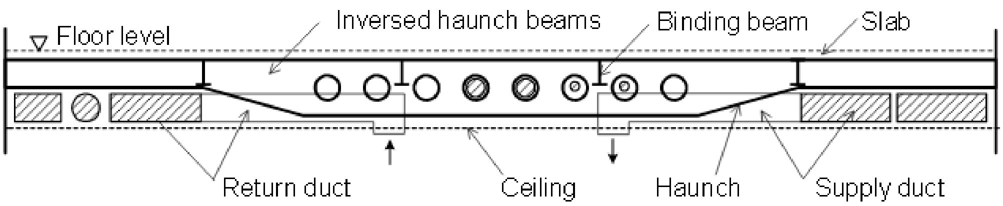


Figure 3. Free mechanical space

The characteristics of individual key techniques for the HMT are described below.

II. OUTER FRAMES

The composition of the outer frames is shown in Figure 4. They comprised efficiently hybrid structure of reinforced concrete columns and steel beams. The reinforced concrete provided strength against vertical force applied to the column, and the steel provided strength against bending force applied to the beam. Because the outer frames bear a little of the earthquake force, they can be generally designed for permanent load. Accordingly, the beams can be used the same member in all the layers. Precast columns with the same bar arrangement could be used, in which the compression strength of concrete was increased for the lower stories. Steel plates were installed in the column at the beam flange levels. These panels and steel beams were jointed with high tension bolts. Therefore, this structure streamlined construction and saved cost.

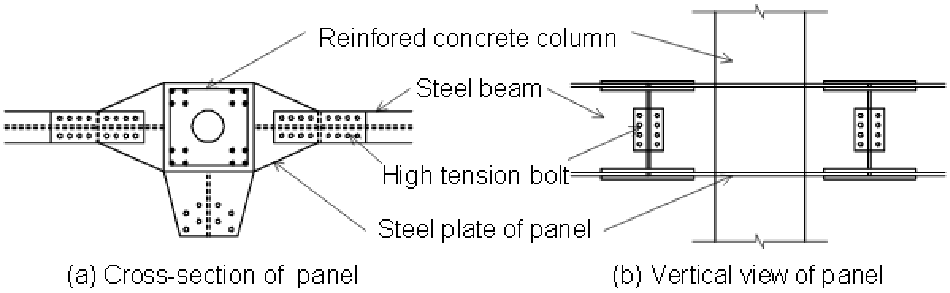
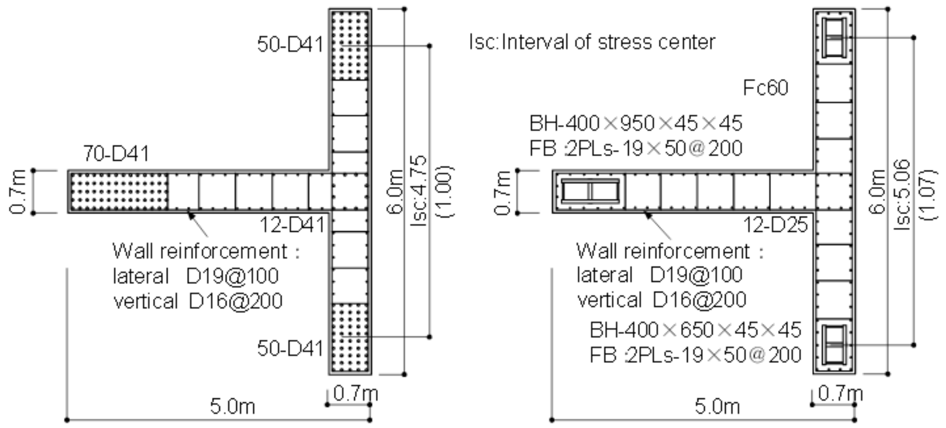


Figure 4. Composition of the outer frame

Earthquake-resisting walls with built-in steel Cross-sections of conventional reinforced concrete earthquake-resisting wall and earthquake-resisting wall with built-in steel are shown in Figure 5. Many large-diameter bending resistance reinforcing bars are arranged at each end of the wall, if there are designed by a conventional reinforced-concrete wall. Vertically connecting mechanical joints increase cost and construction time.



(a)Cross-sections of conventional reinforced concrete earthquake-resisting wall

(b)Cross-section of earthquake-resisting wall with built-in steel

Figure 5. Conventional reinforced-concrete wall and earthquake-resisting wall with built-in steel

Furthermore, because a large number of the reinforcing bars is required, bending performance is impaired where these reinforcing bars to resist bending are located near the center of the cross-section. To solve these problems, these reinforcing bars were replaced with steel frames, bending resistance members were integrated and joints that used reinforcing bars were removed. Moreover, the bar arrangement for the wall was made with lap joints with small-diameter reinforcing bars under 19mm. Therefore, this improved the bending performance and streamlined construction.

III. BOUNDARY BEAMS

The composition of the boundary beam is shown in Figure 6. The energy dissipation capability was improved by converting second-step reinforcing bars to X-shaped steel bars. The PVA-ECC is mixed vinylon fibers (length 12mm and diameter 0.04mm) into the cement mortar. This PVA-ECC is capable of maintaining strength up to a tensile strain of 3%, and is expected to ensure fine cracks and decrease damage. PVA-ECC is a kind of high performance fiber reinforced cementations composite (HPFRCC). This boundary beams have the function of a seismic response control device. Energy dissipation is realized from the yield of the reinforcing bars caused by deformation of the core walls during an earthquake

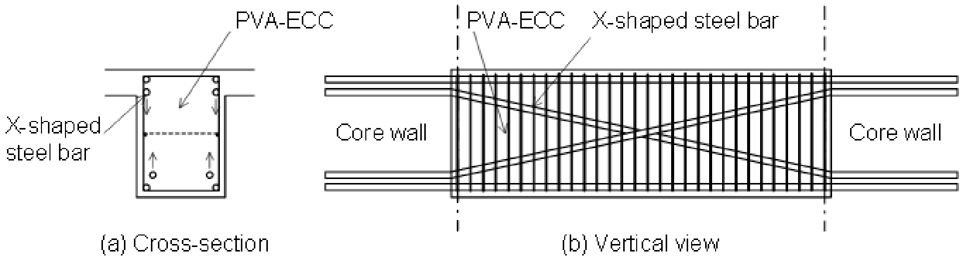


Figure 6. Composition of the boundary beam

IV. THE OVERALL SEISMIC PERFORMANCE OF THE STRUCTURE

For dual system of frame-core wall structure, core wall is the key lateral load resistant member bearing more than 80% earthquake shear force. In order to improve the ductility of the core shear walls steel columns of HM 340×250×9×14 were embedded at the four corners of the core wall and the intersections of longitudinal and transversal core shear-walls which would also be considered as the second proof to the shear wall in avoidance of potential consecutive collapse owing to the degradation of its vertical bearing capacity from the serious cracking of the concrete under rarely occurring earthquake. On the other hand the embedded steel column also enhances the anchorage of the floor truss/beam. While as, in order to strengthen the inelastic deformation capacity of the longitudinal coupling beams carried steel trusses and ensure the integrity character of the core wall, steel shapes were encased inside the coupling beams, which were connected with embedded steel columns forming the embedded steel frames within the longitudinal core shear-walls. In this project the analysis of overall structure is processed in two stages; the first stage is the elastic analysis under the action of frequently occurring earthquake, in

which the response spectrum method for modal analysis was used to calculate all the members' bearing capacity and the elastic story drifts. The second stage is elasto-plastic time-history analysis under the action of rarely occurring earthquake, which is used to calculate and check the elasto-plastic story drifts.

V. CONCLUSION

(1) For dual system of frame-core wall structure, core wall is the key lateral load resistant member, which should be

Strengthened during design to ensure its ductility and bearing capacity. Analysis and test results show that the composite steel and concrete frame-core structure is adequate for high seismic region after rational design and properly embedded steel shapes within the core wall, which has better seismic performance, the interaction between core wall and its surrounding ductility moment-resistant frame is efficient.

(2)Usually the floor truss (beam)-concrete wall connection is assumed as hinged, however the results of finite element analysis and cyclic loading test of specimens as well as shaking table test show the partial restraining moment at the floor truss (beam) end still exist under the action of earthquake, it should be considered during design.

(3) The embedded anchor for the connection between floor Failure of Headed Stud Anchor truss (beam) and concrete wall should be adopted carefully. During design It is suggested to apply to the major bearing members in high seismic regions.

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