Development of wooden semi-rigid frame with improved column and proposal of design methods

Masahiro Noguchi

Structural Engineering Research Center, Tokyo Institute of Technology

Wooden houses are one of the largest utilizations of timbers in Japan. However, in Japan, the life cycles of most houses are around 20-30 years. Recycle ratio of timber as the material resources such as chips and reuses were said around 15 %, including energy resources of around 30 %. This might be considered as the wastes of resources and energies from the global environment perspective. The most governing factor is said that the needs to renewal several equipments and arrangements of rooms can not be met, so-called durability due to the old fashioned uses of the houses, when family organizations and owners change.
As a solution of these problems, open building systems was focused. The open building systems are the building systems that structures were divided into the skeleton parts and the infill parts. Houses were built with the skeleton structures and then owners make the infill such as partition walls and housing equipments and so on. When owners will change, the skeletons allow free partitions of spaces and exchange the housing equipments by future owners. This result in increasing durability of houses.

To develop the skeleton structures, rigid frames whose each node is connected as (semi-) rigid was focused. Because the characteristics of semi-rigid frame structures have following three adaptable characteristics to the skeleton structures, dispensable for shear walls to seismic and wind loads, larger spans to the hinge joints, and adaptable to the present building and structural styles.

Many wooden semi-rigid frame structures now were built, but they always have two problems, too expensive compared with the steel and reinforced concrete structures, and short bays between columns. This is because the shortages of structural performances of wooden semi-rigid frames. Thus, it is necessary to develop semi-rigid frame structures having more effective structural performances.

Moreover, there is another essential problem, the design methods have not been established. Traditional structural styles which have not established structural calculation ways had traditionally changed into the style having structural calculation ways. It was also well-known that the structures designed with structural calculations avoided the big damages under Hanshin-Awaji disaster, although lots of wooden structures without structural calculations were collapsed or damaged a lot. As building and structures are not mass-products, to establish the structural design methods are essential requirements in practice. From above, the key wards of this thesis were set "developments of semi-rigid frame structures with effective structural performances" and "establishing structural design methods of the wooden semi-rigid frame structures".

Firstly, the design methods of knee joints using glued in steel rods (GIR), and cross-lapped glued joints (CLJ) were proposed. In CLJ, I made the hypothesis that both rotational deformation of CLJ and the stress of glue line occurred due to the bending and shear deformation of timber. In GIR, not only the pulling component of rod but also lateral stress component of rod can be taken in account using "theory of the beam on an elastic foundation". From the comparisons between calculations and experimental result, it was recognized that the stiffness and strength in CLJ, and GIR are in good agreement and can therefore be predicted using my models. Therefore, it was thought that the lateral component in the rod has a significant factor for stiffness and strength estimation of GIR. My hypothesis for CLJ can be thought valid within the range of experiments done in this investigation. [1]

In 2nd, a new design method of bolted timber joint was proposed. Considering semi-slip conditions, "moment = 0" and "shear force is equilibrium at the interface between main member and side member, easy formulas for slip modulus and yield strength of bolted timber to timber joint could be derived using "theory of the beam on an elastic foundation". Shear tests having 16 conditions of timber to timber bolted joint whose load angle were varied from 0° to 90° step 30° were performed. From the results, the followings were concluded:

(1) Thinking of 'Semi-slip condition', estimating method of Kuenzi could be simplified.
(2) From results of simulation concerning 15000 combinations, I could derive a kind of closed-form equation to estimate yield load based on TBEF for practical design method. [2]

In 3rd, a new design method of bolted cross lapped joint was developed to estimate the performance of bolted timber joints, in more practical manner, not based on computer simulation. From the theoretical and experimental results, it can be concluded that the rotational stiffness and yield moment in bolted cross-lapped joints can be precisely predicted by using the proposed theory. In the case of rectangular bolt arrangement,

the rotational stiffness calculated using conventional theory is about twice as much as experimental results. Therefore, it is not reasonable to use conventional theory for estimating rotational stiffness in the case of the rectangular arrangement of bolts, but we should use my proposal design method. [3]

Finally, two types of wooden semi-rigid frame structures were proposed. Both structures have improved columns. First type was the structures changed the location of moment resisting ductile joint with improved columns. The second type of structure whose panel zone was extended using improved column. From the test results, the stiffness were improved around 1.7 and 3.5 times as large as that of control, the strength were improved around 1.25 and 1.45 times, respectively. Therefore, the semi-rigid frame structures with improved columns have structural advantages, especially in stiffness. [4]

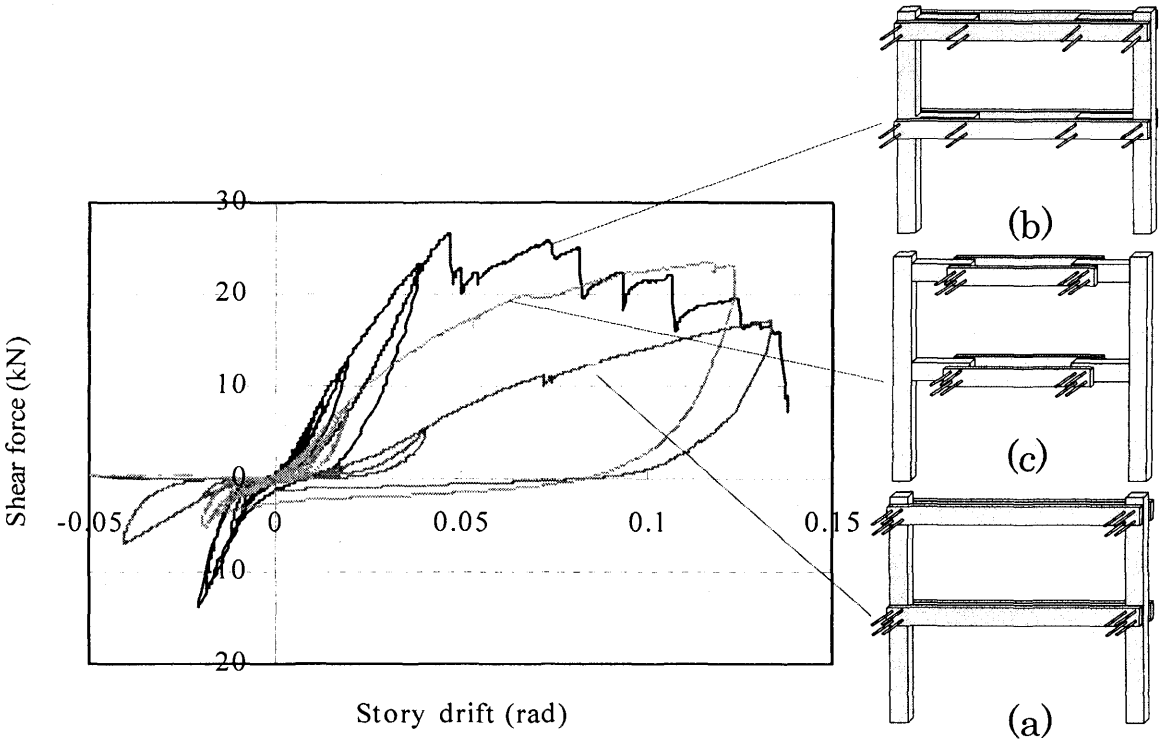

Fig. 1 Shear force-Shear deformation angle relationship
Legend: (a) The structure with traditional bolted cross lapped joints
(b) Proposed structure whose panel zones were extended with the improved column
(c) Proposed structures changed the location of moment transmitting connection with improved columns

In conclusion, this thesis proposes two semi-rigid timber frames with a more effective structural performance are compared and a structural design method is derived. Usually the joints are located at the intersection of the beam and the column. The first frame type applies two types of joints. A high strength capacity rigid glued joint is used to replace the traditional beam-to-column joint while a second ductile semi-rigid joint is positioned at the area with low bending moments.. The beam pieces that run between the column and the semi-rigid joints are so well fixed to the column that they form one integral part. In the second frame type the horizontal beam between the columns is extended beyond the location of the semi-rigid joints of the first frame. This creates a large overlapping area where mechanical fasteners such as bolts are generously spaced. Due to the large fastener spacing the stiffness is enhanced as well as the strength.

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