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Design of High-Rise Building using Round Tubular Steel Composite Columns

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Summary

This paper is a brief report on a specific case of building structural design wherein possible advantages of composite structures were pursued intensively. The paper will give at the outset an overview of the composite structures commonly used in Japan, then it will describe some advantages that may be expected from tubular steel composite columns (and also from high quality high strength steel used to form such composite columns), and finally the paper will describe the essence of the captioned structural design.

1. Composite Structures Commonly Used in Japan

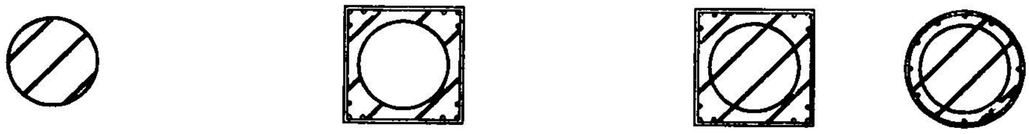
Composite structures certainly have their own advantages; however, if their advantages are to be utilized to a full extent, the characteristics of each component must be used for a fitting purpose and all the component to display its intrinsic merits fully and to supplement at the same time any demerits of other components in order to ensure excellent structures. In Japan, structures are made "composite" at various levels and stages. For example, we have composite materials, composite members, composite structures and composite frames. Glass fiber reinforced concrete (known as GRC) which is composed of concrete mixed with glass fibers to give it some tensile strength may be cited as a case of making it "composite" at the material level. Structural members formed by structural steel combined with reinforced concrete which are extensively used in Japan, composite beams consisting of steel beams and reinforced concrete slabs, composite floors formed by factory-made precast concrete slabs combined with in-site concrete slabs and walls made in a similar manner are also very popular. At the structure level, composite structures are seen in which reinforced concrete members having high rigidity are combined with lightweight ductile steel members in forming vertical and horizontal elements. As regards framing types, large scale frame systems composed of "super frames" and "subframes," which are often used for very tall buildings may be taken as a good example of composite frames.

Among this variety of composite elements, this paper deals with composite columns formed by round tubular steel filled and covered with concrete.

2. Some Structural Advantages of Round Tubular Steel Composite Columns

Round tubular steel composite columns may be defined as composite columns made up of round steel tubes filled and covered with concrete. Having been considered as structural element which makes effective use of merits of each of its components, this type of columns have been studied rather intensively by many engineers for research and development. Composite columns made up of steel tubes and concrete may generally be divided according to their structural types into the following three categories as shown in Fig. 1.

(1) Tubular steel columns filled with concrete
(2) Tubular steel columns covered with concrete
(3) Tubular steel columns filled and covered with concrete



(1) Tubular steel columns filled with concrete (2) Tubular steel columns covered with concrete (3) Tubular steel columns filled and covered with concrete

Fig. 1 Types of Composite Column Structure

Since round steel tubes are simple in cross sectional shape, they can be readily filled and/or covered with concrete. Design advantages that can be expected from the round steel tubes used for columns and making them into composite columns are as enumerated below.

- Round Steel Tubes
  - Since they have non-directional cross sections, they can be expected to display enough bearing strength against lateral force applied to them in diagonal direction.
  - In case the columns are connected to girders in diagonal direction, connections can be detailed easily.
  - As basic material, round steel tubes have excellent industrial productivity.
  - Round steel tubes make it easier to utilize automatic welding by industrial robots in welding operation.

- Composite Columns
  - Composite effects help increase rigidity and strength of columns.
  - Local buckling of steel tubes can be avoided by the composite effects.
  - Fire resistance of steel columns is improved.

For these reasons, it is expected that the use of composite columns consisting of round steel tubes and concrete in high -rise buildings will further increase as buildings are diversified in types, material strength is increased and construction process is industrialized.

In the high-rise building described in the following paragraphs, columns composed of steel tubes in-filled and covered with concrete used. In the open space at the base of this building, composite columns formed by tubes made of high quality high strength steel having 590 N/mm^2 tensile strength (here in after reffered to as "high strength steel") and high strength concrete were employed.

The term “high quality high strength steel” is used here to mean such high tensile steel which displays comparatively little yield point variations and has a low yield ratio (i.e. a low yield point-tensile strength ratio). In other words, the term means high strength steel that shows high energy-absorbing performance. In earthquake-prone Japan, primary consideration must be given in building design to the building’s behaviors during a seismic event. To cope with an extremely severe earthquake which rarely occurs, a design technique is used by which an appropriate parts of the frames are let to enter a plastic range in event of such an earthquake thus enabling seismic energies to be absorbed. Use of high quality high strength steel provides a positive means to absorb great energies, to minimize steel plate thickness and thus to enhance workability.

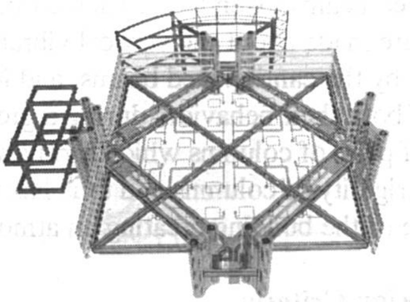
The case introduced here indicated that the use of composite columns formed by high strength steel tubes and high strength concrete is an effective way to enable columns to carry great axial loads.

3. A Case of A High-rise Building Using Tubular Steel Columns Filled and Covered with Concrete

3.1 Summary of Design

The building introduced here as an example is a high-rise building with a height of 101.2 m having 21 above ground floors and a basement. Creating “an up-to-date building in the high-tech age” and providing “bright and open office spaces commanding good views” were the primary design concepts. A typical floor plan consisting of the outside core and one-room type office spaces was adopted to ensure maximum space flexibility. Columns were at the mid-point of each exterior wall, and this was conductive to most attractive feature of this building, namely a building commanding nice views.

Fig. 2 External Appearance



Typical Floor Framing Plan

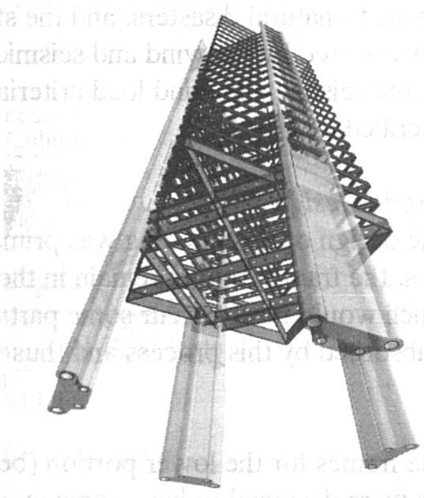


Fig. 3 Framing Perspectives

Structurally, this building is in the form of rigid frames composed of steel tubes filled and covered with concrete and structural steel beams. Each pair of columns is located at mid-point of each exterior wall and one pair of columns is connected to another pair of columns with a pair of bearing girders, thus forming the frames whose corners meet the exterior walls at an angle of 45°. These structural frames or "skeltons" also form utility skeltons. Namely, spaces within the three pairs of columns are used for air conditioning equipment rooms and spaces between pairs of girders are used as main chambers of air conditioning system. Two cross beams are located at each floor level in direction orthogonal to each pair of bearing girders and these cross beams are connected to cantilevered beams supporting exterior walls and floors. Floors are composed of precast concrete slabs of joist type each about 8 m in span. These slabs, free of small subbeams, ensure flexibility in providing piping under these slabs.

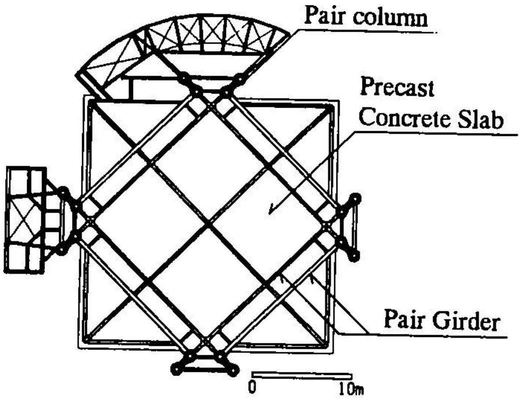


Fig. 4 Framing Plan

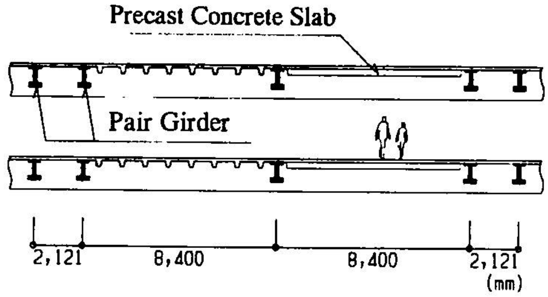


Fig. 5 Section of Typical Floor

Cantilevered beams extended to each corner of the building has a span of about 7 m. Careful studies were made about the vertical vibrations of the floor beams at the corners of the building supported by the cantilevered beams, and it was confirmed that these corners create no problems in respect of both their behaviors during a great seismic event and their habitability at normal times. The use of pairs of columns which form a visual feature of this building has also helped ensure structural rigidity of columns and thus has made it possible to provide open space about 20 m high at the base of the building creating an atmosphere open to the exteriors at the ground level.

3.2 Design Criteria

Japan is prone to natural disasters, and the structural design of any buildings to be constructed here is inevitably affected by the wind and seismic forces which must be taken into account. In this paragraph, the seismic and wind load criteria and some related problems which need to be noted will be described.

3.2.1 Seismic Design

The seismic design of this building was primarily based on the following principles: under moderate earthquakes, the frames should remain in the elastic range, and in event of extremely severe earthquakes which would rarely occur some parts of frames would enter the plastic range but energies would be absorbed by this process and thus serious damage to the building as a whole could be avoided.

Further, the frames for the lower portion (below the third floor level) which is designed as a large open space were designed to have some extra strength so that they would be able to withstand severe earthquakes without damage. In the typical floors, too, the structural elements were so designed that only the beams outside pairs of girders would enter the plastic range while the beams inside them would remain in the elastic range, thus avoiding drastic change in rigidity of the building.

3.2.2 Wind Resistant Design

This building has a complicated configuration both in plan and in elevation. So, needs were felt to ascertain how the building would be structurally affected by its complicated shape. In particular, the structural behaviors of the fan-shaped north side portion where the building has a curved surface and a sharply cut-in part as well as a large open space were thought to require careful studies. Hence, a series of wind tunnel tests were reflected on the structural design.

Through these tests, it was ascertained that the open space at the base of the building could effectively reduce the winds induced by adjacent buildings. Also, in consideration that the existence of a sharply cut-in portion on the north side of the building might cause the building to be twisted by the wind force, such wind effects were ascertained by the wind tests and the design wind loads were determined accordingly.

3.3 Design of Pairs of Columns

A pair of columns located at the center of the exterior walls were made of steel tubes filled and covered with concrete. On the typical floors, round steel tubes (ϕ 660.4 mm) were connected with
H-shaped steel beams, steel tubes were in-filled with concrete, and then by covering both walls and columns integrally with concrete, pairs of columns were formed. Steel tubes were formed by bending a steel plate and ring-shaped forged steel diaphragms were used at joints.

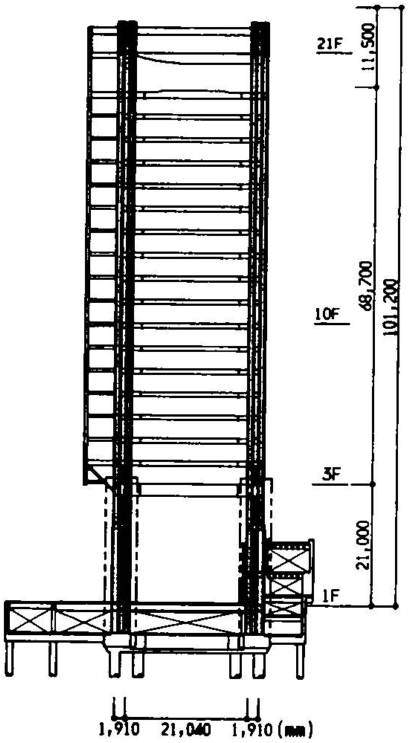


Fig. 6 Framing Elevation

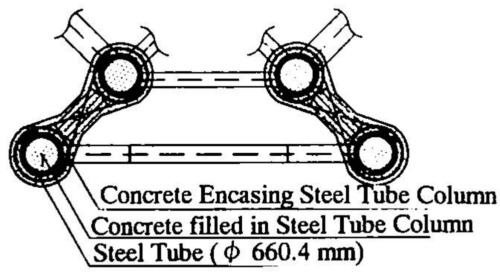


Fig. 7 Section of Pair Column (Typical Floor)

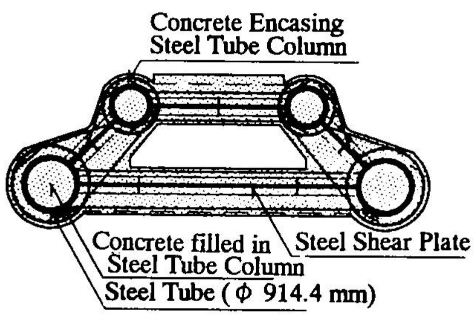


Fig. 8 Section of Pair Column (Large open space)

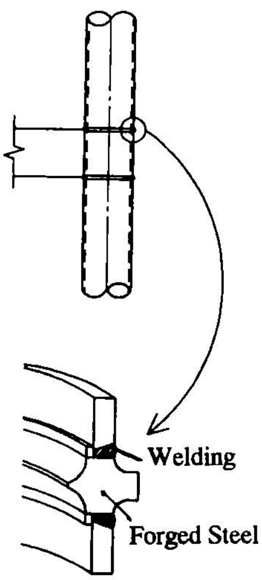


Fig. 9 Formation of Steel Column

The axial force acting on the pair columns in the open space amount to about 4,000 metric tons per pair. Hence, the frames below the third floor level forming a large open space were designed to have large bearing capacities so that they would be able to stay within the elastic range in event of a great earthquake. For the tubular steel columns in this space where they are subjected to high axial force and so must have high rigidity, steel tubes made of high strength steel were used in combination with high strength concrete to ensure the required bearing capacity and rigidity. The use of high strength steel made it possible to reduce the maximum plate thickness to 50 mm for steel tubes 914.4 mm in diameter (i.e., D/t = 18.2, D: diameter t: thickness), and this certainly helped enhance workability, weldability and economy of the connection.

As has been already mentioned, round steel tubes have a shape which is adaptable for automatic welding by means of industrial robots. For construction of this building, robots were used in both factory welding and field welding for column connection.

Placement of concrete into steel tubes was conducted by the use of tremies for each nit height of a column (i.e., equal to the height of three floors or about 12 m).

4. Conclusive Remark

This paper describes the design of a high-rise office building in which pairs of round steel tube (made of high strength steel) composite column were used. The writers believe that a unique and dynamic piece of architecture was realized in this project by using high quality high strength steel and round steel tube composite columns to the best advantage. Further, they expect that the use of high strength steel and high strength concrete in an appropriate combination will expand the potential area of structural design and that this paper indicates such potentiality.

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