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Design and Construction of GINZA KABUKIZA

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Abstract

This paper describes the structural solution for the design of a 29-story high-rise tower, which features a large office space above the Kabukiza Theatre. Kabuki is a type of Japanese traditional drama, and Kabukiza is the home building of Kabuki. GINZA KABUKIZA is the fifth generation of the Kabukiza Theatre, the first of which was built in 1889. In order to support 23 stories of office space above the theater – featuring a large void in plan – two 13-meter-deep mega-trusses, spanning 38.4 meters, are installed at the fifth floor of the building. Steelwork is used as a primary material for the structure above–ground, and a hybrid response control system using a buckling-restrained brace and oil damper is adopted in order to achieve a high seismic performance. This paper also describes the erection process of installing hydraulic jacks directly above the mega-truss at column bases, in order to keep the structure above the truss level during construction. The temple architecture of the previous Kabukiza is carefully restored by incorporating contemporary light-weight materials supported by steelwork.

Keywords: Kabukiza Theatre, Mega-truss, High-rise building, Response-controlled structure, Hydraulic jack

1. Introduction

GINZA KABUKIZA is a large scale project with a total floor area of 94,000 m^2 and overall height of 145.5 m above ground to renew the Kabukiza Theatre, a dedicated venue for Japanese traditional drama called *Kabuki*, and in addition provide offices in Ginza area at the heart of the dense city Tokyo.

The low-rise part of the development, which is the fifth generation Kabukiza Theatre, reproduces as far as possible the external appearance, internal space, acoustics, and other characteristics of the previous fourth-generation theatre that it replaces and which was registered as a tangible cultural property. At the same time, the latest technology and materials have been used to develop it as a state-of-the-art theatre to suit modern needs. (Photo 1 and 2).

Great ingenuity and effort were required at all stages of the project to bring the scheme to fruition. This report is an introduction to the design and construction work, with particular focus on the two large spanning Mega-trusses over the theatre.

2. Architectural Outline

The building has 29 stories above ground, which consists

Photo 1. Overall view of the new building.

Photo 2. View of the previous building.

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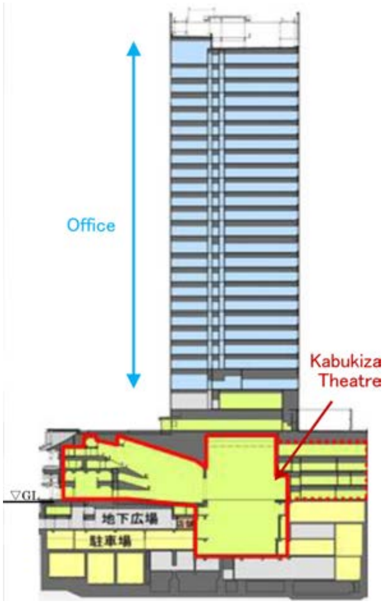


Figure 1. Cross section in elevation.

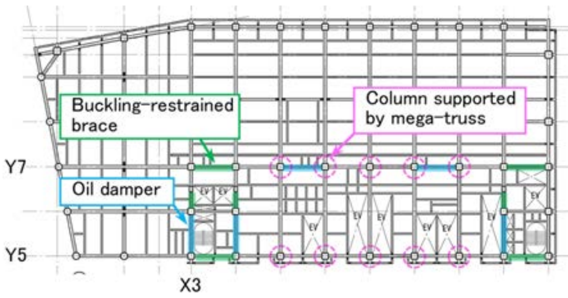


Figure 2. Typical plan.

of a high-rise part with 23 stories for office use and a low-rise part used as a theatre. An intermediate machine room and public contribution facilities (gallery and rooftop garden) are provided in the area between the low-rise part and the high-rise part.

The low-rise Kabukiza Theatre includes an auditorium and stage space extending over four stories and configured as a large atrium. The exterior appearance of the previous theatre, which has become a symbol of the Ginza area, was revived (Fig. 1).

The typical plan of the high-rise part is a rectangle measuring about 70 m on the long side and 33 m on the short side. There is a 20 m span of office space with no columns on the north side, with core functions on the south side. The façade of the south side core of the high-rise part is finished in PC (Pre-cast Concrete) panels carrying the motif of a lattice window in traditional Japanese architecture (*nerikorenji*). This provides a background against which the Kabukiza Theatre stands out.

3. Structural Design Concept

A steelwork structure was adopted to ensure high seismic performance for the multi-purpose building in which the tower is built directly above the theatre.

The high-rise tower provides offices from the seventh floor upward. Under the high-rise tower, the theatre occupies space up to the fourth floor with an area about twice of the high-rise part. Between these functional spaces, the fifth and sixth floors act as transition floors, where the systems are switched between the large low-rise theatre space and the high-rise office space above it. A feature of the structural scheme is the provision of two Mega-trusses that supports 10 columns on the south side of the high-rise part (core side sections Y5, Y7). (Fig. 2) With this design, the efficient standard span of the high-rise part is maintained, while at the same time realizing a large open space in the low-rise part. The transition floors include an intermediate machine room and spaces for spreading out service ducts and pipes. These facilities are used by both the office and theatre functions in accordance with the services scheme. In addition, people going to offices switch at the seventh floor sky lobby and use the elevator shaft in the core section of the office typical floor plan. As a result, the transition floors have a complex function and are designed with a rational scheme.

Another measure adopted to procure adequate space for the theatre was to incline the nine columns on the north side from the 5th to 8th floors, providing an offset in column position of 1.6 m (Fig. 4).

The building stands on a raft foundation. With a Mega-truss providing a large span space below, one of the issues faced was the design of the foundation beams. The solution was to create a "wall beam" by integrating using foundation beams with a load-resisting wall on the lowermost floor, taking into consideration load transfer between the various sections: Mega-truss – low-rise part – foundations – ground (Fig. 3).

There are several examples of schemes in which a high-rise building stands above a large open space on an intermediate truss, including the Tokyo Takarazuka Theatre [1] and others. However, this project is special from the point of view of the span and depth of the Mega-truss and the load supported on one plane.

4. Type of Structure and Seismic Design Targets

The superstructure is basically a moment resisting structure using structural steelwork and CFT (concrete filled tube). Hysteretic and viscous response control devices (dampers) form a hybrid response-controlled structure for the high-rise part, to achieve high seismic safety as well as a rational standard floor design. In the low-rise part the important structural features are the columns supporting the Mega-truss and associated large beams, the structure

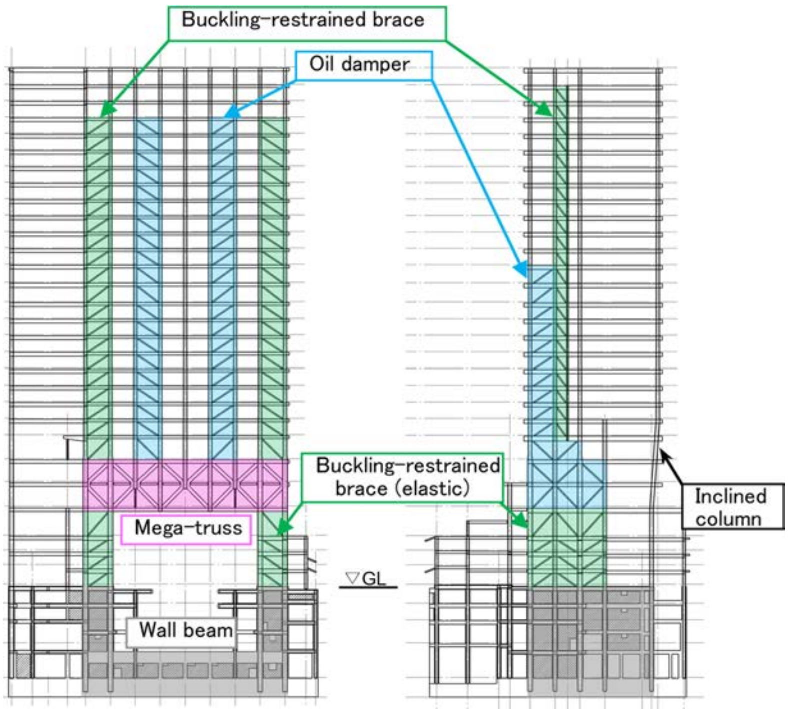


Figure 3. Y7 Elevation. **Figure 4.** X3 Elevation.

of the tiled roof, and the complex non-structural members in the internal and external finish of the theatre that are used to create the Kabukiza ambience. The low-rise part of the building was designed with a large margin of seismic safety to reduce deformation and damage during an earthquake by installing elastic type of buckling-restrained braces, whose strength of the core steelwork is 490 N/mm^2. The seismic design target of the low-rise part of the building was set as follows. The structure would be mostly elastic and maximum relative angle of deformation would be less than 1/150 approx., under very rare i.e., 500 years' return-period earthquake. Fig. 5 shows the maximum angle of relative deformation as the result of dynamic analyses. In X direction, including the Mega-truss frame, response of the low-rise part is small, while in Y direction, the overall building deforms in a good balance.

5. Design of the Mega-truss

The span of the Mega-truss is 38.4 m and it has a depth of approximately 13 m. The total long term axial load of the columns supported by the Mega-truss (at section Y7) is about 9000 tons. Sufficient stiffness is ensured such that the target deflection is 30 mm or less with respect to the long term load, equivalent to an angular deviation of about 1/1200 (ignoring the vertical stiffness of the Vierendeel structure above the truss).

A high level of safety is designed into the Mega-truss by ensuring that stresses generated in truss members were less than the allowable short term stresses, even under combined loading conditions that include the effects of vertical seismic motion during major earthquakes. The strength of steelwork used was 490, 550 and 590 N/mm^2. The basic truss cross-section is a welded box cross-section measuring 900 mm × 900 mm with a maximum plate thickness of 85 mm (Fig. 6).

6. Fabrication of the Mega-truss

A careful study was carried out to formulate fabrication procedures and control standards for the Mega-truss, paying particular attention to the fact that it consists of large cross-sections of thick plate requiring welding in various positions.

6.1. Study of member shapes

In investigating the member shapes in detail, in addition to the normal drawing-based checks, verification was also carried out using 1/10 scale models, full size film, and 1/1 models. After the drawing check, 1/10 scale models were constructed to verify the suitability of the plate patterns, the through system of overlap weld lines, and the assembly procedure. Based on this verification, a further investigation was carried out using full size film and 1/1 models to determine the bevel shapes, backing plate shapes and positions, range of ultrasonic inspection tests required, and accuracy control methods (Photo 3).

6.2. Study of on-site welding

On-site welding of the top and bottom chords of the

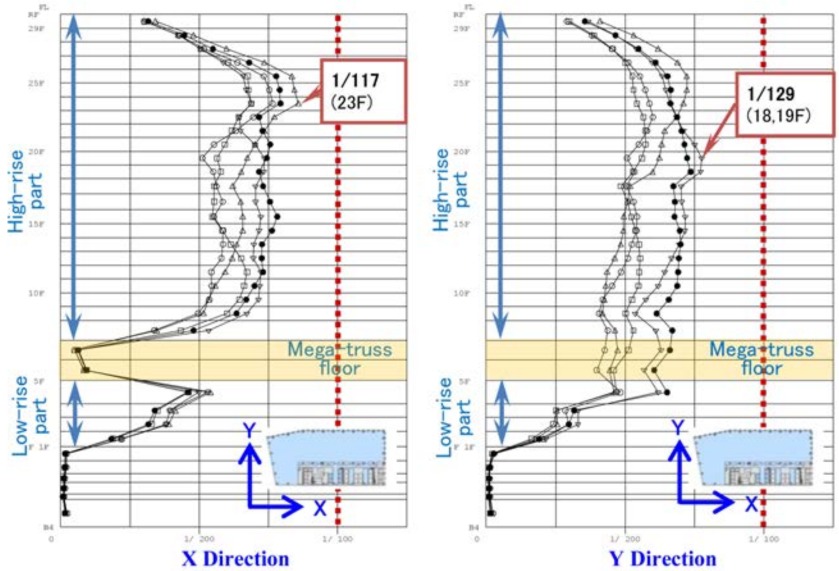


Figure 5. Maximum angle of relative deformation (very rare earthquake level).

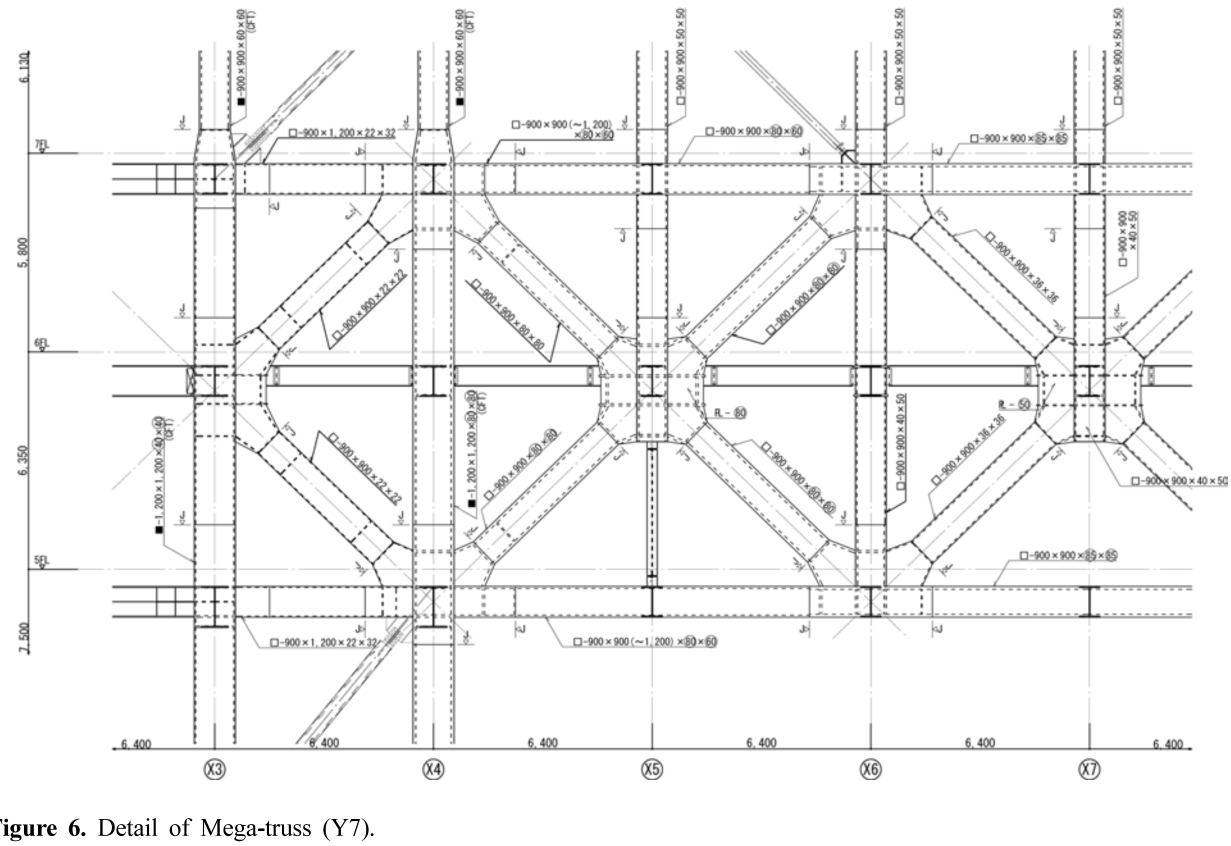


Figure 6. Detail of Mega-truss (Y7).

Mega-truss required welding in the downward and vertical orientations, without the need for inverted welding. On the other hand, the undersides of diagonals had to be completed in the inverted orientation, while the side faces were welded on the inclined vertical. With welding of this complexity, trial welding tests were carried out to ensure that the required quality could be obtained.

For ease of working, inverted on-site welding was carried out with a 30 degree V groove shape (15 degrees from the centre) on four faces and with a root gap of 11 mm. Weld-

Photo 3. 1/1 size model.

Photo 4. Welding test (inverted).

ing tests were carried out in advance using specimens with the same shape and position, confirming that there would be no problems of weldability and that adequate quality could be obtained. The test welds were examined by visual inspection, ultrasonic inspection tests, and macro tests (Photo 4).

On-site inclined vertical welding gave rise to concerns over excessive weaving, excessive heat input, and reduced performance of the steelwork material. Welding tests were carried out in advance using specimens with the same shape and position so as to investigate the effect of changes in bead width on mechanical properties. From the results of the tests, control values such as bead width per pass and the inter-pass temperature, etc., were established. From these values, appropriate construction conditions for on-site welding were determined (Photo 5).

Photo 5. Welding test (inclined vertical).

6.3. Prefabrication

One intersection of diagonals of the truss was fabricated in advance as a trial to allow for verification of assembly procedures and welding shrinkage. One objective of prefabrication was to confirm fabrication accuracy in advance of actual construction. It was intended that these parts would be re-fabricated, but the accuracy of the trial pieces, as determined through various investigations such as the model tests, was good, so the prefabricated parts were used as part of the actual Mega-truss.

Photo 6. Temporary assembly study.

6.4. Trial assembly test

A trial assembly was carried out in the factory as a product test of the Mega-truss. The dimensional accuracy of the assembled truss and measures to cope with discrepancies in on-site welded parts were established (Photo 6).

By investigating measurement methods in advance, it was verified that discrepancies in on-site welded parts could be controlled if measurements were made before and after welding. In this way it was possible to re-confirm measurements and confirm the methods of improvement for quality control.

6.5. Verification of the method of erection

As the members of the Mega-truss are very large, they were erected using a stacking procedure similar to using building blocks. Accuracy of assembly was ensured by metal-to-metal contact against backing plates on panels of columns, diagonals, and intersections. On the other hand, for beam members that were to be dropped in, backing plates were fitted on site and clearance for the root gap was adjusted during erection.

In order to achieve erection accuracy, hydraulic jacks were installed on the bent gantry when erecting the bottom chord members. Also, because the members are large and adjustments would be difficult after erection, every effort was made during erection to improve accuracy by carrying out measurements and making adjustments several times

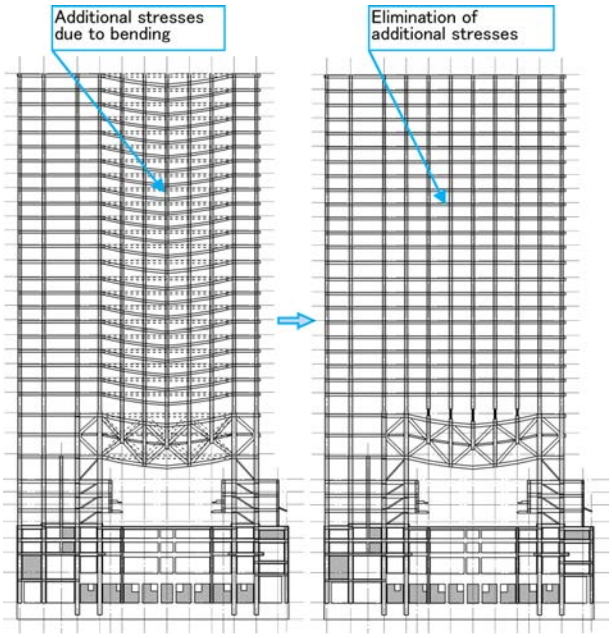


Figure 7. Elimination of additional stresses by jacking.

Photo 7. Hydraulic jack.

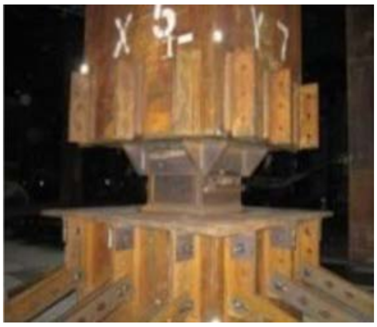


Photo 8. Sand jack.

at each stage.

Further, in order to reduce the effect of welding shrinkage on finished dimensions as much as possible, the welding sequence for on-site welded parts was determined with great care.

7. Jacking up on Mega-truss

There was concern that, if normal construction procedures were adopted, large additional stresses would be imposed on the upper structure (at sections Y5, Y7) due to the Vierendeel effect caused by vertical bending of the Mega-truss occurring during construction. In order to eliminate these stresses, it was decided early in the design stage to control vertical deflections at the points where the columns connect to the top of the Mega-truss during construction. It was decided to jack up the columns to match the bending produced by construction of the upper floors in order to maintain a horizontal alignment of the main beams of the upper floors. In this way, a rational frame design was achieved for the standard floors, and harmful deformations were prevented in the façade, etc., associated with construction of the upper floors.

Further, jacking ensured that the long term axial loadings of the columns on the Mega-truss were reliably transferred to the Mega-truss, while redistribution of the vertical loading, which was a concern in the event that the upper floors' Vierendeel structure became plastic during a major earthquake, was avoided (Fig. 7).

7.1. Construction plan

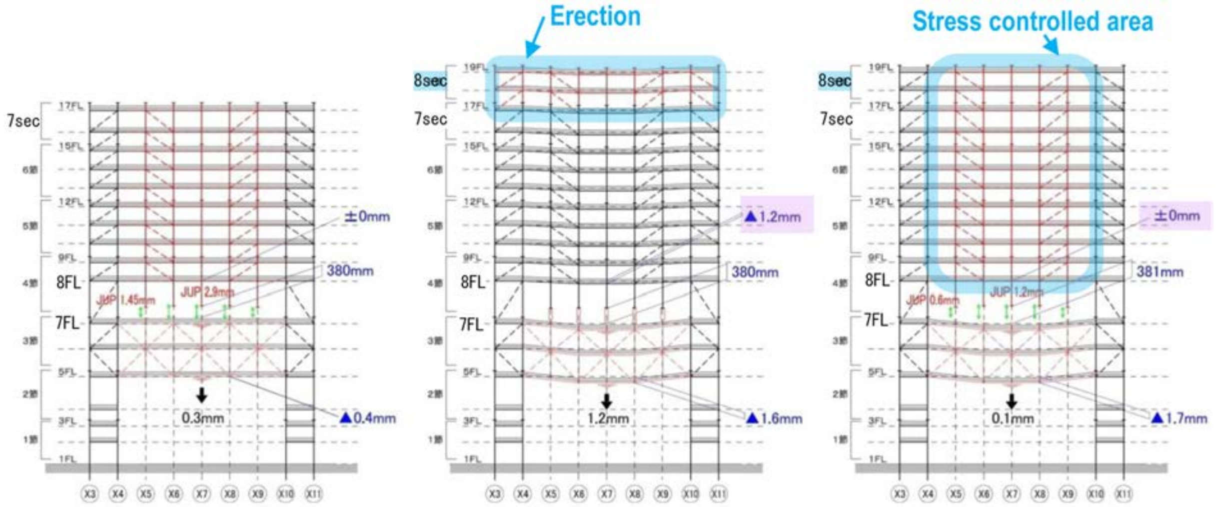
The construction procedure entailed installing hydraulic jacks at the base of the 7th floor columns directly above the top chord (Photo 7). The columns were jacked up in accordance with the deflection of the Mega-truss arising from the increasing load as construction progressed. At each construction step, the deflection of the 8th floor beams was measured, and the jacks were controlled to restore them to horizontal.

The specific procedure [erect structural steelwork] → [measure deflection] → [control deflection] → [erect next stage of structural steelwork] was repeated. After jacking up, the axial load was temporarily supported on sand jacks. A sand jack is a temporary load-carrying device without a jacking up mechanism in which the load is supported by sand compacted in a box (Photo 8). After completion of the structure on all upper floors, skin plates were welded at the positions of the hydraulic jacks. The sand was then extracted to allow the skin plates to carry the axial load.

Tests were carried out in advance on the use of sand jacks to determine the effect of the deformation of the sand and the side pressure when loaded, and to determine the amount of settlement and rebound of the sand.

7.2. Analysis of construction

An analysis was carried out to determine the amount of jacking required during the construction process. First, the integrity of the members was analytically checked at each



After jacking-up 7th section

Erection of 8th section (jack temporarily fixed)

After jacking-up 8th section

Figure 8. Method of erection above the Mega-truss and displacement control.

step, under the assumption that jacking would be carried out at every step. At the same time, the behaviour of the Mega-truss and the structure above it, the jack reactions and the jack strokes were determined. From this analysis, it was confirmed that jacking would be possible until the final step and that the proposed construction method was feasible (Fig. 8).

Next, a re-analysis was carried out taking the construction schedule into consideration. As a result, it was decided to carry out jacking operations four times, with the final jacking up step prior to completion of erection. When determining the timing of the final jacking step, the deflection produced in subsequent steps was predicted and, by including this in the amount, it was possible to achieve deflections in accordance with the final target.

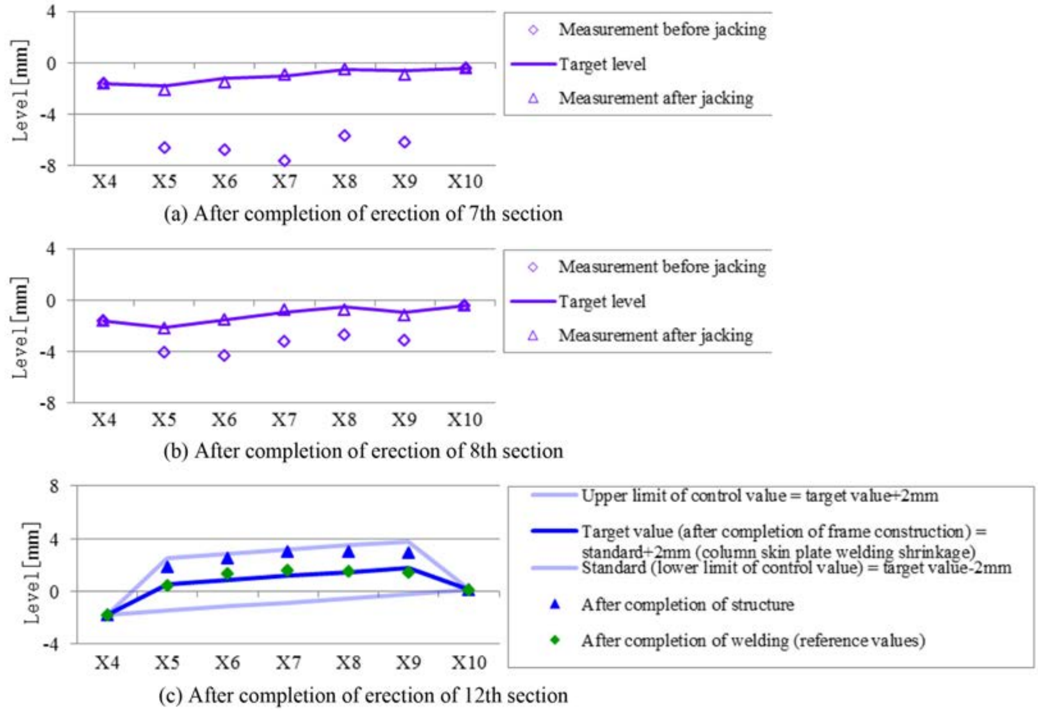


Figure 9. Measurement results before and after jacking.

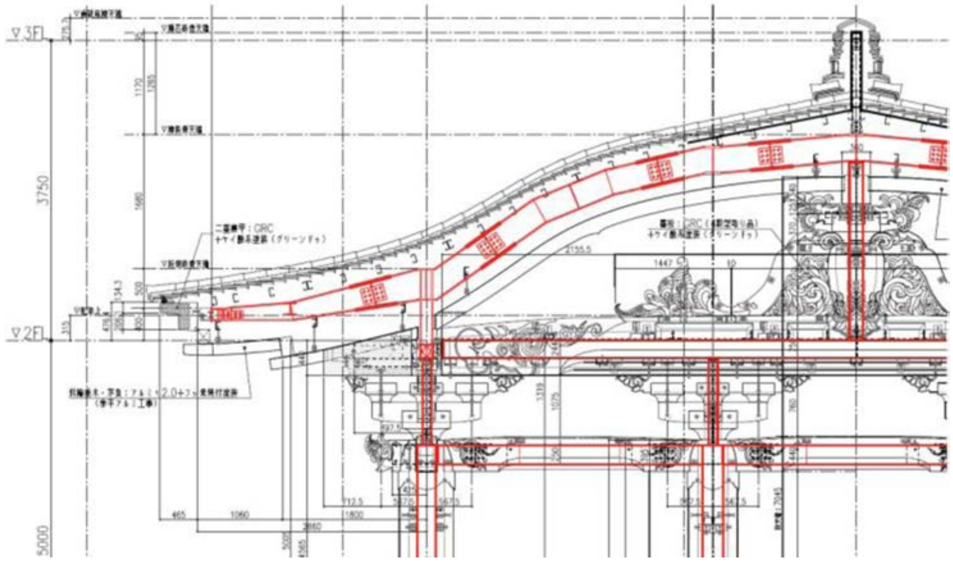


Figure 10. Details of *Karahafu*-style gable and concealing the structural steelwork.

7.3. Measurement results

Measurement of vertical deflections was carried out after completion of each jacking operation and after completion of the upper floor structure. As a result of good understanding of the jacks' characteristics, careful jack control, and knowledge of welding shrinkage, etc., a high accuracy of ±2 mm was achieved (Fig. 9).

8. Reproduction of Temple Architecture using Structural Steelwork

The façade of the previous Kabukiza Theatre was in the style of Japanese temple architecture. It was built with the reinforced concrete technology of the Taisho Period (1912-1926). On this project, structural steelwork was chosen instead, but in order to reproduce the previous façade without visible load-bearing members, modern materials such as PC, GRC (Glass-fibre Reinforced Cement), and aluminium were incorporated.

8.1. Roof truss structural steelwork

In order to reproduce the roof trusses of the characteristic tiled roof of Kabukiza in structural steelwork in accordance with the original dimensions, it was necessary to lay out the internal structural steelwork in a small spatial volume. The detailed fit was checked by preparing CAD drawings that included the positional relationship of all finishes for each type of construction. A full size film was prepared at the master carpenter's factory floor and, through discussions that took into consideration the detailed constructability and maintainability, the structural steelwork was manually drawn directly into the film. Adopting such method is very rare today when mechanization by CAD and specialization is so advanced. As a result, it was possible to easily determine the fit of the façade materials, including the tiles, onto the underlying structural steelwork (Fig. 10, Photos 9 to 11).

Photo 9. Entering structural steelwork onto full size drawing.

Photo 10. *Karahafu*-style gable structural steelwork.

Photo 11. *Karahafu*-style gable.

Photo 12. Mock-up of edge of eaves.

8.2. Mock-up of façade

In order to verify the finish of the façade, a mock-up was produced. Constructability, including that of the underlying structural steelwork, was confirmed using this mock-up.

In a normal mock-up, which is designed to illustrate the external appearance only, the underlying structure is generally different from that of the actual building. However, in the mock-up for the corner of the eaves, underlying structural steelwork detailed as for the actual building was fabricated and constructed so as to verify installation procedures and confirm constructability (Photo 12).

9. Conclusion

This paper describes the design and construction of the Mega-truss, a major component in the structural design of GINZA KABUKIZA. Also described is the reproduction of the façade in the style of traditional temple architecture using structural steelwork. Highly accurate construction of the highest quality was achieved through the technological capabilities of the contractor and steelwork fabricators, as well as through close consultation and cooperation among these entities and the design firm.

To conclude, we would like to thank all those concerned on the client side at Shochiku Co., Ltd. and Kabuki-za Co., Ltd. for giving us the valuable opportunity to take on this project.

References

[1] Sugibayashi, H., Asou, N., Yagi, T., Yoshida, M., Masumura, K., and Hoshi, M. (2001) "Design and construction of Tokyo Takarazuka Building," *Journal of Steel Structures & Construction (JSSC)*, 40(April), 28-35.