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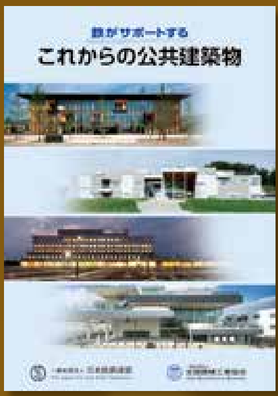
Feature Article

Towards Promotion of Steel-structure Construction of Public Buildings



Serial Article: Latest Design of Steel Buildings in Japan (6)

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Steel Supports the Future Construction of Public Buildings

Emerging Tasks Involved in Public Building Construction

Superannuating Public Facilities and Steel Structures

A pressing task is emerging in Japan—the issue of the ongoing superannuation of social infrastructure constructed in the high economic growth period in the 1960s, and appropriate measures to cope with such a situation are required to be promptly implemented. In particular, schools, government offices, hospitals and other public buildings are undergoing remarkable superannuation, and public buildings constructed during the period from the late 1960s to the early 1970s have entered into the renewal stage.

In Japan, most non-residential buildings are constructed with steel structures. On the other hand, reinforced-concrete (RC) structures have been adopted for the construction of most public buildings, particularly school buildings. However, steel-structures are increasingly being adopted in the construction of public buildings due to changes in societal environments such as:

- Need for new facility improvement measures with which building space and application can flexibly be changed so as to meet changes in population movement in the future and building function to be required
- Remarkable shortage of skilled workers engaged in RC construction, such as those working in reinforcing bar arrangement and form assembly

Steel structures can redundantly resist earthquakes, and because the structure is composed of stable-quality structural members manufactured and fabricated at shops, it can be said that steel structures are suitable for the construction of public buildings for which high seismic safety is required.

Steel Industry Initiatives for the Wider Application of Steel Structures

The Japan Iron and Steel Federation (JISF) established in 2014 the Committee on the Promotion of the Steel Construction of Public Buildings, which has so far extended extensive efforts for promoting steel-structure application in the construction of schools, hospitals, and other public buildings where steel-structure application levels have been low. Under collaboration with the Japan Steel Fabricators Association, JISF has distributed steel-structure promotional brochures to local governments, design offices and general contractors nationwide and has held related courses for them (Photo 1).

In addition, JISF has established the Subcommittee on the Survey and Research on Public Buildings Employing Steel Structures within the Japanese Society of Steel Construction. Learned persons in the field of building plans, particularly of living environments, those working in practical design and construction and researchers of design and construction companies have participated in the Subcommittee, which has conducted surveys and research on the following subjects:

- Analysis of the specific performance of steel structures vis-à-vis the function required for public buildings, and the trial calculation of construction costs employing trial designs
- Survey of the noise-, vibration- and thermal-insulation performance of steel structures involved in the living environment, and the examination of points of cares to be given in the design of steel-structure buildings

Photo 1 Course to promote steel-structure application held by JISF

New Functions and Requirements in Public Building Construction

While many public facilities have entered into the renewal stage, societal conditions surrounding public buildings show radical changes, and the function and application required for these buildings are diversifying and becoming more sophisticated. It is required for public facilities to function as not only a core operating base but also a disaster prevention base for people living in the local community. On the other hand, the recent financial restrictions imposed on local governments call for less maintenance and construction costs and longer service life for public facilities. (Refer to Figs. 1 and 2)

Fig. 1 Societal Conditions and Needs Surrounding Public Facilities

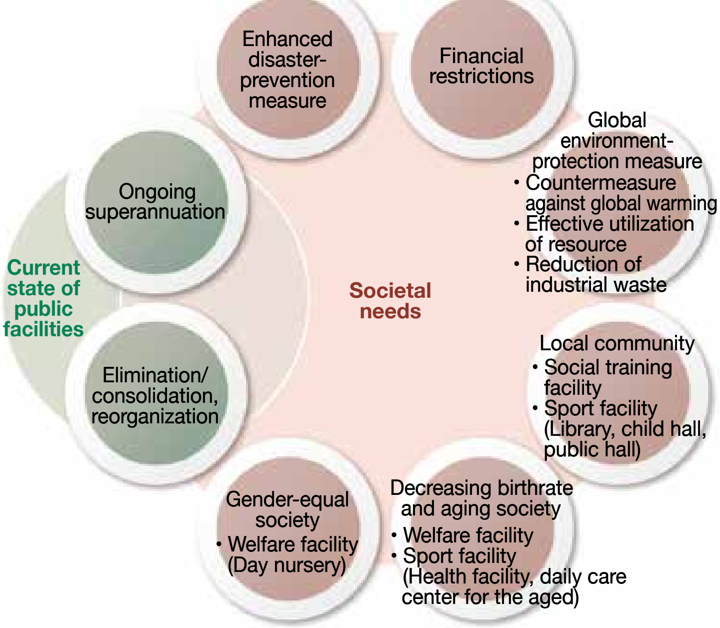

Fig. 2 Functions Required for Public Facilities to Possess and Tasks Requiring Further Examination

Applications	Functions required in usual time	Functions required in the event of disaster	Tasks requiring examination
School	• Safe and secure place • Core facility in the regional community Complex use as public hall Opening of gymnasium and library	• Evacuation facility for those living in neighboring areas	• Response to change in student number and population movement
Government office	• User-friendly and ease-of-use facility • Suppression of equipment and running costs	• Response to business continuity program (BCP) • Disaster response headquarters	• Response to change in population movement (change of service to be required)
Hospital	• Safe and secure place • Comfortable space for patients • Building plan that is high in working efficiency and easy in working for staff	• Response to business continuity program • Accommodation of mass injured persons	• Replacement of medical equipment; response to aging society and reforming of system (response to increase/decrease of sickbed number)

Steel Solutions Conducive to Dealing with Emerging Tasks in Public Building Construction

For public buildings, there is a call for functions that can appropriately meet changing societal needs, and certain tasks to cope with such a need are becoming apparent. In dealing with such emerging tasks, characteristic features peculiar to steel structures may serve as an effective solution.

Given such situations, JISF's Committee on the Promotion of Steel Construction of Public Buildings has recently published a revised steel-structure promotional brochure titled *"Steel Supports the Future Construction of Public Buildings"* (Photo 2). It assesses the role and performance of steel structures conducive to solving these tasks as seen in the following:

Optimized Use of Features Peculiar to Steel Structures

• Response to Complex Use and Application Change

It is required for public buildings to promote effective facility operation for complex uses and to flexibly meet changing needs. Steel structures can secure wider space with less column installation. Flexible space can be created by the use of steel structure.

• Reduction of Construction Term and Cost

In the construction of public buildings, shorter construction periods and the reduction of construction cost and maintenance cost are important requisites. Steel structures can reduce the construction term over RC structures.

• Provision for Disasters

It is required for public facilities to function as a disaster-prevention base in the event of disaster. Steel is a material high in toughness, strength and ductility. Seismic energy is absorbed by steel's own deformation capacity to prevent the collapse of buildings. Steel structures are suitable for the construction of the disaster-prevention base (evacuation site) for which high seismic safety is required to be provided.

• Reduction of Environmental Load

Environmental friendliness is an important element required for public buildings. Steel can be recycled without construction waste. Steel is an eco-friendly material that allows reuse.

(Refer to Fig. 3)

Trial Design and Cost Comparison of Steel-structure School Buildings

Trial design was made for school buildings employing steel structure and RC structures to compare the construction cost between these two structures. It was learned from the trial design that the total cost of steel structures was cheaper than that of RC structure due to a sharp reduction of foundation pile work costs caused by the lightweight construction of the upper structure and to the reduced on-site management costs caused by the shorter construction term. Further, it was also learned that in terms of the maintenance cost, steel structures were preferable over RC structures.

Verification of Habitability of Steel-structure Buildings

Some project owners and designers have fears that the sound-insulation and vibration-damping performance of steel structures are inferior to those of RC structures. Targeting school buildings employing steel structures and RC structures, sound insulation and vibration damping were surveyed. Further, assuming the school building, the sound environment and temperature/thermal environment were analyzed.

• Survey of Sound Environments

Targeting primary school buildings employing steel-structures and RC-structures, the floor impact sound insulation performance was measured. Because of the difference in floor specifications subjected to surveys, a simple comparison between these two structures could not be conducted, but it was confirmed that the steel structure offered the floor impact sound insulation performance required for classroom floors.

• Analysis of Heavyweight Impact Sounds

The vibration response of steel-structure and RC-structure models was analyzed. No clear difference between them was recognized.

• Analysis of Walking Vibrations

Walking-simulated vibration was analyzed. It was confirmed that both steel structures and RC structures have enough habitability to resist walking vibrations.

• Analysis of Annual Thermal Load

Assuming a 3-story school building, the thermal load imposed on steel-structure and RC-structure models was calculated. No remarkable difference of air-conditioning load between them was recognized, and further it was confirmed that the structural difference did not materially affect the air-conditioning load.

Outstanding Examples in Public Building Construction Employing Steel Structures

Main reasons why steel structures are adopted are as follows:

- Realization of column-free open space
- Feasible lightweight construction because of unstable ground conditions
- Reduction of construction term
- Reduction of construction cost
- High compatibility with timber materials

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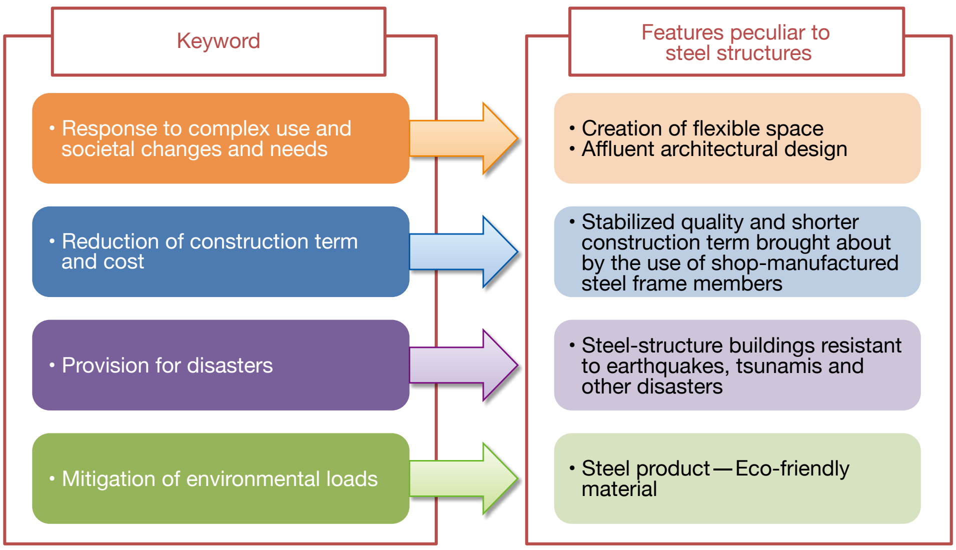
How steel structures can contribute to the future construction of public buildings is introduced in more detail in the following pages:

Fig. 3 Keywords for Public Building Construction in the Coming Generation and Features of Steel Structures



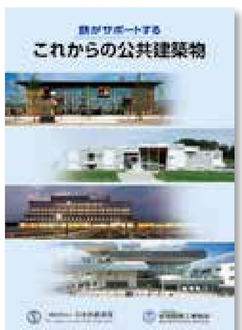


Photo 2 Steel-structure promotional brochure

Optimized Use of Features Peculiar to Steel Structures

Response to Complex Uses and Application Changes

For public buildings in the coming generation, there is a need to meet diverse needs and functions, among which are:

Efficient Improvement of Public Facilities Capitalizing on Complex Uses

Schools and other similar public facilities have so far been prepared for single application purpose. However, from the viewpoint of financial restrictions, improved convenience for the community and effective land utilization, it is required to efficiently prepare public facilities that capitalize on complex uses. (Fig. 1)

Flexible Response to Changing Needs

Due to the declining birthrate and ongoing aging society and the trend toward more compact living spheres in the community, the population and age composition are showing steady changes, which poses new requirements for public buildings—building structures that allow not only flexible changes in internal layout and application but also efficient use over the long term.

Column-free Wide Space and Freedom in Room Layout

A notable feature of steel-structure buildings lies in their wide spaces with less columns. For facilities required to provide wide open spaces, it can be said that steel structures are the appropriate structural system. Because of less structural restrictions such as no installation of fixed walls (bearing wall) in steel-structure buildings, it is possible to design free plane plans with the use of steel structures. In addition, when movable partitions are adopted in steel-structure buildings, it is easy to change the room layout.(See Photos 1 and 2)

Long Service Life-oriented Facilities to Flexibly Meet Changes in Application and Layout

In common steel-structure buildings, the wall members do not bear the structural strength. Because of this, the wall can be removed or installed in conformity with change in future needs and without damaging the structural members, and accordingly the building application and room layout can easily be changed.

In short, steel structures are a structural system that allows the construction of "long service life-oriented public facilities" for which efficient utilization over the long term becomes feasible.

Securement of Effective Space

One of the attractive points in steel-structure buildings is the narrow section of columns. That is, even in an identical floor area, as the area occupied by columns is narrower, the applicable building space increases.

Further, because of the low height of steel beams, it becomes possible to secure the required ceiling height while suppressing an increase of story height or settling the story height to a low level.

Affluent Architectural Design

Because wide openings can be provided with the use of steel structures, bright, open indoor spaces can also be provided. Further, high workability peculiar to steel structures can offer diverse architectural designs such as fine curving and hybrid use with timber (Photo 3) and other locally produced structural members.

Photo 1 Column-free working room found in a steel-structure building

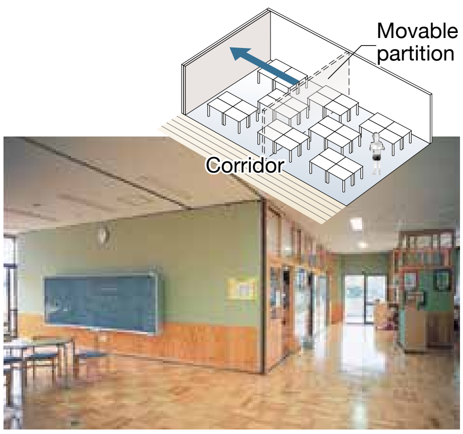
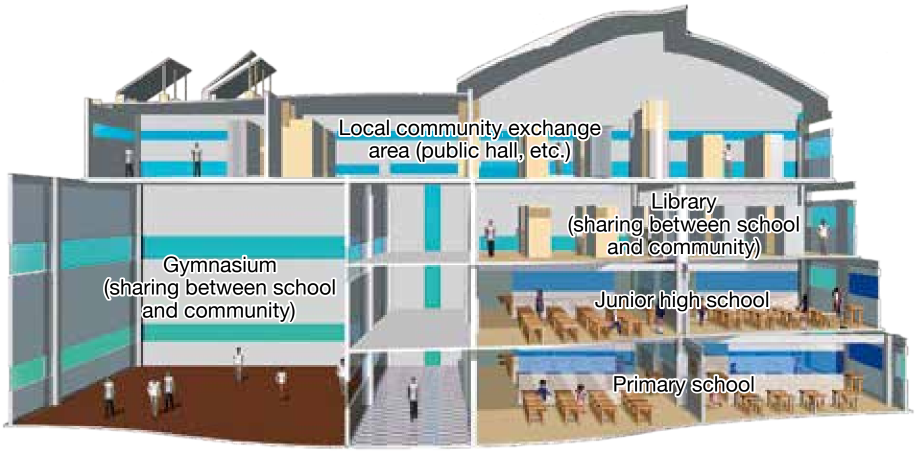


Photo 2 Classroom layout change employing movable partitions

Photo 3 Timber-steel hybrid structural member (fireproof member is put into practical use)
Source: Japan Laminated Wood Products Association

Fig. 1 Image of Complex Facility Building of Public Function-intensive Type



Reduction of Construction Term and Cost

In the construction of public buildings, an important issue is the reduction of construction costs.

Because steel-structure members are shop-manufactured, their quality is stable. In addition, it can be expected for the steel structure to reduce on-site construction term and construction cost. On top of this, less on-site work brought about by the reduced construction term also leads to the mitigation of various loads imposed on those living in neighboring areas and users.

Stable Quality Obtained from Industrial Production

Because of the shop manufacture and fabrication of steel structural members, their quality is stable. The steel structure is assembled at the site by means of bolt fastening and simple welding, and thus the building quality is not apt to be governed by the skill level of on-site workers, which thus allows the stable construction of high-quality buildings.

Reduction of Construction Term due to Reduced On-site Work

In the construction of RC-structure buildings, reinforcing steel bars are arranged at the construction site and concrete is poured into the form to erect the building structure floor by floor. In contrast, in the construction of steel-structure buildings, steel structural members shop-fabricated in advance are carried into the construction site to assemble the building structure, which thus does not require complicated on-site work. Accordingly, the construction work can be proceeded without impacts from a shortage of labor or weather conditions, which thus allows the reduction of construction terms. (Refer to Figs. 2 and 3)

Mitigation of Diverse Loads around Construction Site

Because of the reduced on-site work, the emission of dust and waste materials and occurrence of noises can be prevented.

Because of this, when construction work is promoted at sites close to residential areas, the mental burdens imposed on residents around the site can be mitigated. Further, the usage term of the land and parking lot around the construction site can be shortened, which leads to the reduction of the cost involved in construction site management.

Reduction of Construction Costs

One of the structural features brought about by the use of steel structures is the possibility for the lightweight construction of the upper building structure, which allows a sharp reduction of construction costs including piling work costs when compared to RC structures. In addition, the steel structure allows the reduction of on-site management costs due to the reduced construction term. (Refer to Fig. 4)

Reduction of Maintenance Costs

The exterior walls of RC structures are not maintenance-free, and periodical maintenance is required to prevent the neutralization of concrete. On the other hand, the application of highly-durable exterior walls in steel-structure buildings can suppress maintenance costs to a low level.

Fig. 2 Reduction of On-site Work

Steel structures	RC structures
Steel frames are shop-fabricated in advance, and fabricated frames are carried into the construction site and assembled at the site, which requires no complicated on-site work.	Reinforcing bars are arranged at the construction site and concrete is poured into forms to erect the building structure one story by one story.

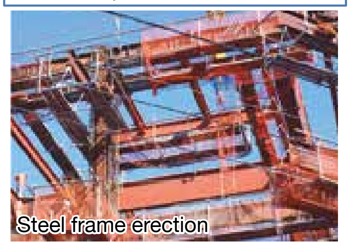


Fig. 3 Comparison of Construction Term between Steel Structures and RC Structures (Example of Medium-rise Building)

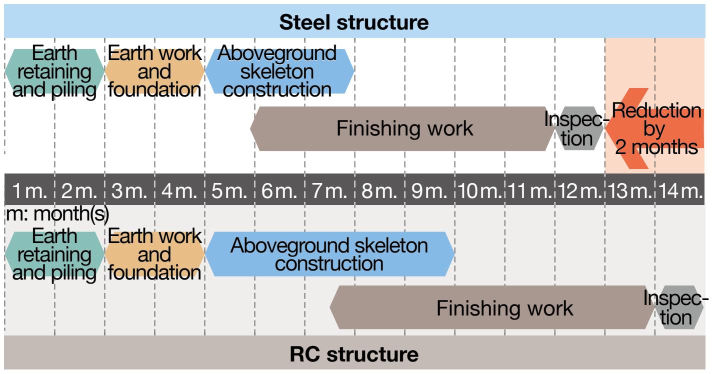
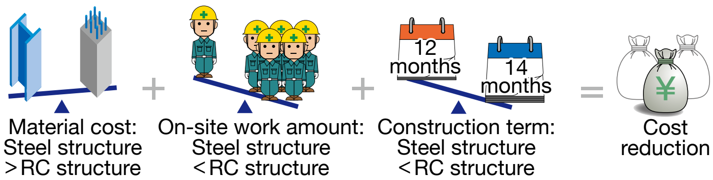


Fig. 4 Comparison of Costs between Steel Structures and RC Structures



Provisions for Disasters

For government offices, hospitals, and other public facilities, there is a need to function as a disaster-prevention base (evacuation site) in the event of disaster, and thus it is necessary to take possible means to handle earthquakes and tsunamis. Steel structures support the construction of public facilities that are highly resistant to disasters.

Provisions for Earthquakes

Steel structures tenaciously resist seismic vibration. Steel is a structural material that is high in toughness, and thus the seismic energy is absorbed capitalizing on the optimum use of its own deformation capacity, which thus prevents the collapse of buildings.

In order to further improve the seismic safety of steel-structure buildings, building vibration is reduced by the use of vibration-control dampers (buckling-restraint braces, etc.) and isolators (laminated rubber, etc.), which also allows the mitigation of damage to columns and beams (Photo 4). Steel structures are a structural system suitable for the construction of disaster-prevention bases requiring high seismic safety.

Another advantage of steel-structure application is easy maintenance after being subjected to earthquakes. In steel structures, structural members and finishing members (exterior wall, etc.) are separately installed, and thus maintenance work can more easily be implemented compared to the repairing of cracks that occur

Photo 4 Example of base isolator

in RC structures (Photo 5). Steel structures allows the mitigation of repair costs.

As a measure to handle seismic force, base-isolation steel-structure buildings are increasingly being constructed. Because the steel structure is light in weight, the number of base-isolation devices to be installed can be decreased. Base-isolation devices are high-priced members, and when the installation number is decreased, the building construction cost can be reduced by a wide margin. (Refer to Fig. 5)

Photo 5 In RC-structure walls, cracking and concrete peeling are apt to occur in the event of earthquake.

Provisions for Tsunamis

Based on the survey results of damage in the Great East Japan Earthquake, technical standards concerning tsunami evacuation buildings were established in 2011. With their establishment, it has become possible to design tsunami evacuation buildings employing steel structures. (Refer to Figs. 6 and 7, and Photo 6)

Fig. 5 Seismic-resistant Building Construction

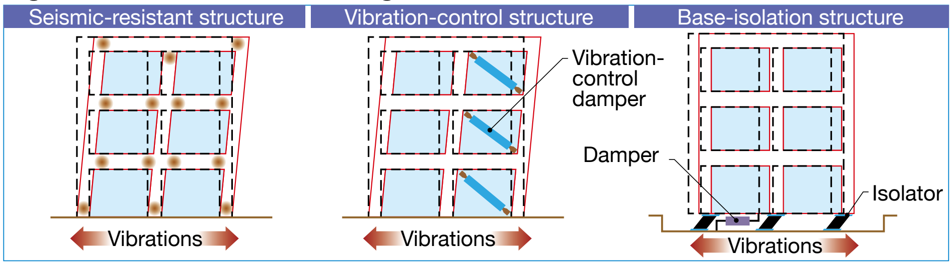


Fig. 6 Calculation Method for Tsunami Wave Pressure

Tsunami wave pressure is calculated as the static hydraulic pressure with a height obtained by multiplying design inundation depth *h* by water depth coefficient *a*.

a: Water depth coefficient
h: Design inundation depth (m)
p: Unit volume mass of water (t/m³)
g: Gravity acceleration (m/s²)

	Shielded		Not shielded
Distance from shore or river bank	500 m or more	Less than 500 m	No relation with distance
Water depth coefficient *a*	1.5	2	3

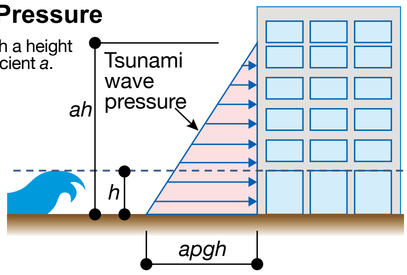
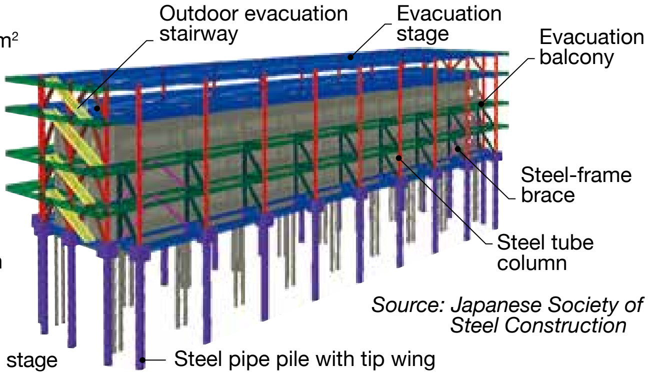


Fig. 7 Example of Design of Seismic- and Tsunami-resistant Reinforcement of Existing RC-structure School Buildings using Steel Structures

Outline of building
- 3 stories aboveground; Total floor area of 2,005 m²

Outline of reinforcement
- Additional installation of steel-frame with steel braces on peripheral section of existing school building
- Installation of steel-structure evacuation stage by taking into account application as tsunami evacuation facility
- Support of evacuation stage by the use of steel tube column newly installed at peripheral section of existing building
- New installation of screwing pipe piles aiming at overturning prevention, sliding prevention, brace pull-out resistance and load support of evacuation stage



Source: Japanese Society of Steel Construction

Photo 6 Mitigation of tsunami external force by means of the installation of pilotis at low-rise section of building

Mitigation of Environmental Loads

Today it is required for public buildings to be "eco- and human-friendly facilities." The human-friendliness (barrier free), the necessity to pay due consideration to the peripheral environment and other requirements described in the specifications can easily be solved at the structural design stage. Then, what should happen to public buildings after they finish their service life?

Steel—Ultimate Eco-friendly Material

For buildings to be built in the future, it is required to pay due attention to the lifecycle cost (cost covering from building construction and maintenance to demolition and disposal). Far before the term "eco-friendliness" spread in society, steel has properly been recycled for reuse. Steel is an outstanding structural material in terms of recycling.

• Reduction of Construction Waste Emissions

Because steel products can be recycled, no construction waste is emitted, which leads to the reduction of waste treatment costs. Steel is conducive to solving a pressing task, the shortage of waste disposal sites.

• Saving of Resources

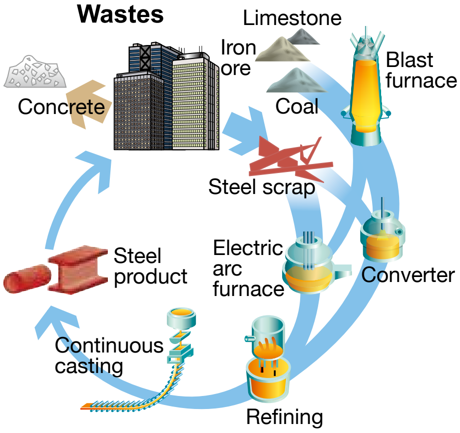
Steel is an ultimate eco-friendly material that can be reused repeatedly by means of decomposition and regeneration of recycled steel products. The steel industry does not waste iron, an important resource presented from the earth. (Fig. 8)

• Long Service Life Buildings

Among notable structural advantages derived from the use of steel structures are the large-span construction and no need for seismic-resistant walls. It can be said that steel structures are the structural system most suitable for the renovation of buildings.

Towards realizing a "sustainable society for the coming generation" from the "scrap and build society" we have experienced, steel structures support the construction of long service life buildings that can flexibly meet even changes in application in the future.

Fig. 8 Conceptual Diagram of Steel Recycling from Construction Wastes



Trial Design and Cost Comparison of Steel-structure School Building

In the construction of a junior high-school building to be newly constructed due to the integration and abolishment of existing schools, the Committee on the Promotion of Steel Construction of Public Buildings of the Japan Iron and Steel Federation has proposed a school building employing a steel structure.

The proposed school building can flexibly meet future changes in both student numbers and application capitalizing on the steel structure. Further, due consideration has been given to the complex use of the school building as not only a disaster-prevention base in the event of disaster but also a facility for the use of local communities.

Based on this proposition, the Subcommittee on the Survey and Research on Public Buildings Employing Steel Structures of the Japanese Society of Steel Construction has made a trial design of this steel-structure school building and a trial calculation of the initial cost for the school building in the case of adopting a steel structure or an RC structure in its construction.

Outline of Building Plan

- 4 stories aboveground; Total floor area: 4,963 m^2
- Ordinary classrooms: 12 classes (4 classes × 3 grades)
- Exchange of students between grades and utilization by local communities by providing an atrium space on the 2nd floor (installation of a stair that can enter directly into the 2nd floor)
- Installation of top light on the 2nd-floor atrium to utilize natural light
- Adoption of highly-durable extrusion-formed cement board for exterior wall
- Application of rooftop as an evacuation space (Photo 1)

Outline of Building Structure

- Longer span (8.1×10.8 m) than the span of general school buildings and moment-frame structural type by taking into account future application change
- Safety coefficient as a disaster-prevention base: 1.25; Structural calculation: Route 3
- Foundation pile type: Cast-in-place concrete pile (L=29 m) (Figs. 1 and 2)

Comparison of Cost between Steel-structure and RC-structure Buildings

Targeting the trial design of the steel-structure school building (4-story building with a total floor area of 4,963 m^2) introduced above, the construction cost in the case of adopting both the steel structure and the RC structure was compared.

The building construction cost was low for the steel structure that could sharply reduce the piling work cost due to lightweight construction of the upper building structure. Even for the building requiring no piling work, because it can be expected for the steel structure to reduce the construction term by about 2 months over the RC structure, the steel structure was lower than the RC structure in terms of the total cost. In addition, because the section of the structural members to be applied could be made smaller in the steel structure, wider effective space became available. (Table 1, Fig. 3)

Further, in the steel structure for which the exterior wall material could be freely chosen, the maintenance cost could be suppressed to a low level by the use of highly-durable exterior wall members (extrusion-formed cement boards, etc.). (Fig. 4)

Photo 1 Appearance perspective of steel-structure school building

Fig. 1 3rd-floor Framing Plan

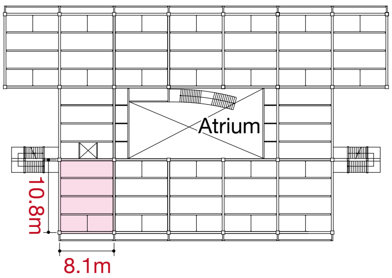


Fig. 2 Framing Elevation (span direction)

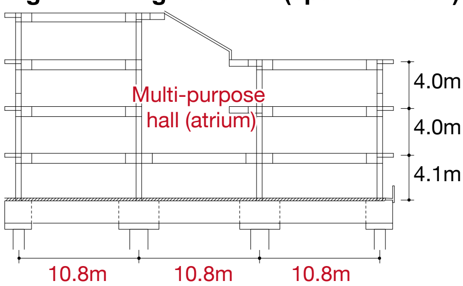


Table 1 Comparison of Cost between Steel Structures and RC Structures (¥1,000)

Item		Steel structure	RC structure
Building structure		238,364	271,342
	Column	□-500×16-22 (BCR295)	□-800×900~□600×1150 (Fc30~33)
	Beam	H-488×300~H-800×300 (SN490B)	□-600×950~□-650×1150 (Fc30~33)
Finishing		323,072	288,183
	Exterior wall	Extrusion-formed cement board	Exposed reinforced concrete + Coating
	Interior wall	Gypsum board with lightweight steel beds (Exterior wall section: Spraying of thermal insulation material*)	
	Window	Double-layer glass	
Fire protection (sprayed rock-wool)		12,371	–
Earth work		24,277	27,100
Piling		83,000	156,000
	Cast-in-place (L=29 m)	Φ1600~1900	Φ2000
Total cost		681,084	742,625

*Additional cost reduction due to reduced construction term can be expected for the steel structure.

Fig. 3 Construction Cost (Initial Cost)

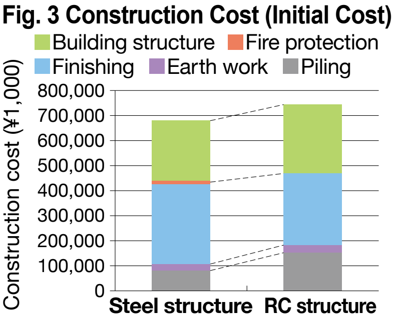
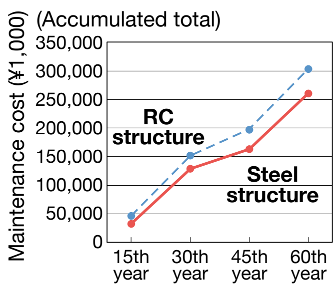


Fig. 4 Maintenance Cost

Calculation conditions

- The durable year is set at 60 years, and maintenance is carried out every 15 years.
- The exterior wall of steel structures is subjected to partial repair (20%), and that of RC structures is recoated every 15 years. The sealing material used for both structures is replaced every 15 years.
- As regards the interior, waterproof layer and other sections, identical maintenance is carried out for both structures.



Verification of Habitability of Steel-structure Buildings

Living environments (insulation of sound, vibration, heat and other elements) are an important factor required for public buildings. Some project owners and designers seem to have fears that the sound-insulation and vibration-damping performance of steel structures may be inferior to those of RC structures. In order to promote the construction of steel-structure public buildings, it will be necessary to wipe away such fears.

At the Subcommittee on the Survey and Research on Public Buildings Employing Steel Structure of the Japanese Society of Steel Construction, surveys were made of the sound-insulation performance of school buildings employing steel structures and RC structures. Further, analysis was made of the sound and thermal environments assuming school facilities.

As a result of surveys and analyses, it was confirmed that there was almost no effect of the difference by structural type on the sound insulation performance, walking-induced floor vibration and air-conditioning load. The specific results are as follows:

Survey of Sound Environments

Aiming to understand the sound-insulation performance of the floor structures of public buildings employing steel structures, the floor impact sound-insulation performance of two school buildings employing steel structures and RC structures was measured.

Survey Targets

The steel-structure school building subjected to survey was as follows:

- S primary school in Chiba Prefecture
- Building outline: 2 stories aboveground; total floor area of 7,927 m^2

The RC-structure school building subjected to survey was as follows:

- R primary school in Chiba Prefecture
- Building outline: 3 stories aboveground; total floor area of 4,934 m^2

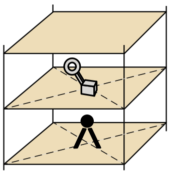
Measurement Methods

The floor impact sound-insulation performance was measured targeting the steel-structure and RC-structure primary school buildings. The floor impact sound was found in conformity with JIS A 1418-1 Measurement of floor impact sound insulation of building: Part 1: Method using standard light impact source and JIS A 1418-2 Measurement of floor impact sound insulation of building: Part 1: Method using standard heavy impact source. (Refer to Fig. 1)

Measurement Results

Because of the difference of floor specifications (double-wall floor in the steel structure), a simple comparison could not be made, but it was confirmed that the steel structure possessed the floor impact sound insulation performance required for classrooms and in dealing with both heavyweight and lightweight impact sources (Table 1 and Fig. 2).

Fig. 1 Survey Method for Sound Insulation Performance




Heavyweight impact source

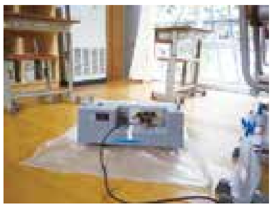
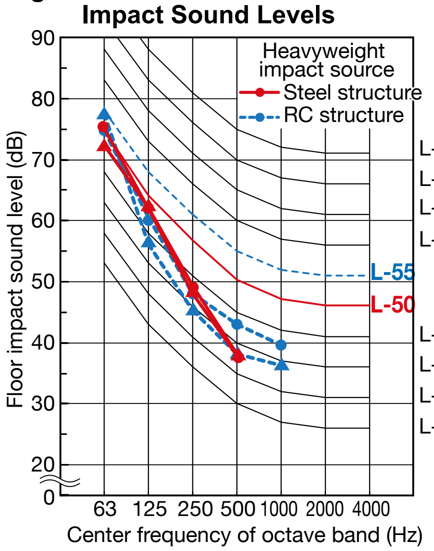

Lightweight impact source

Table 1 Outline of Measurement Results

Building	Measurement room: Sound source room	Measurement room: Width × Depth	Measurement room: Floor specification	Measurement result*: Heavyweight impact	Measurement result*: Lightweight impact
S primary school (steel structure)	2F ordinary classroom (intermediate section of building)	8.4 m × 8.0 m	Floor slab 150 mm Flooring (dry-type double-layer floor)	LH-50 (best class)	LL-50 (best class)
	2F ordinary classroom (corner section of building)			LH-50 (best class)	LL-50 (best class)
R primary school (RC structure)	3F ordinary classroom (RC partition wall)	8.0 m × 8.0 m	Floor slab 180 mm Flooring (finishing by means of direct putting on)	LH-50 (best class)	LL-60 (second class)
	3F ordinary classroom (dry-type partition wall)			LH-55 (first class)	LL-60 (second class)

*Class designation in parenthesis conforms to the guidelines of the Architectural Institute of Japan (best class: highly excellent; first class: excellent; second class: standard).
It is considered that the difference of measurement results between steel structures and RC structures in lightweight impact is notably affected by the difference of floor specifications.

Fig. 2 Measurement Results for Floor Impact Sound Levels



Analysis of Heavyweight Floor Impact Sounds

In order to assess the effect of the difference of structural type (steel and RC structures) on the floor impact sound insulation performance, the heavyweight floor impact sound was analyzed targeting the following analytical models.

Structures Subject to Analysis

Figs. 3 and 4, and Table 2 show an outline of the steel-structure model.

Fig. 5 and Table 3 show an outline of the RC-structure model.

Analytical Cases

Table 4 shows the analytical cases. For the analytical case of S3 (steel-structure with composite floor slab) shown in Table 4, the section of the composite slab (deck plate depth of 50 mm + concrete of 125 mm) was structured to have a weight per unit area nearly similar to that of the RC slab with a thickness of 150 mm.

Analytical Conditions

The in-plane/out-of-plane coupled-type finite element method* was adopted as an approach to analyze the vibration response. Analysis was made by setting the excitation force and the damping performance for every octave band of 31.5~500 Hz bands. For the radiation sound analytical approach, the wave function method* was adopted. (Refer to Figs. 7 and 8)

*Reference: "Study on floor slab vibrations and sound radiation" by N. Hashimoto (thesis of The University of Tokyo)

Fig. 3 Framing Elevation of Steel-structure Model

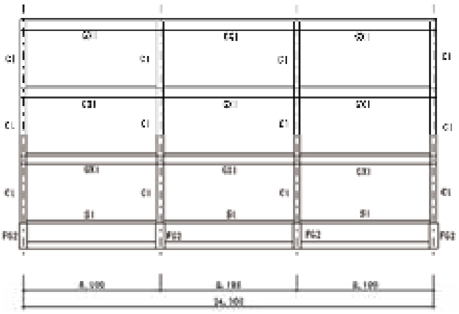


Fig. 4 Framing Plan at 2nd and 3rd Floors of Steel-structure Model

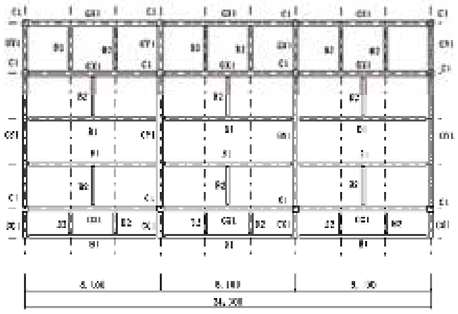


Table 2 Dimensions of Beams and Columns of Steel-structure Model

Beam	Section	Sectional area
Girder GX1	H-500×250×9×16	123.6 cm²
Girder GY1	H-500×250×9×16	123.6 cm²
Beam B1	H-450×200×9×14	95.43 cm²
Beam B2	H-200×100×5.5×8	26.67 cm²

Column	Section	Sectional area
C1	□-350×19	239.2 cm²

Analytical Results

Figs. 9 and 10 show the plane distribution of vibration acceleration level obtained from the vibration response analysis.

When comparing the analytical cases of steel-structure models, the L value (classification of sound insulation) of Models S-2-1 and S-2-2 with steel forms was decreased by 1~3 from that of Model S-1 with an RC slab thickness of 150 mm, which showed an improved sound insulation performance due to the adoption of steel forms. While the unit-area mass of Model S-3 using a composite slab was similar to that of Model S-1, the L value of S-3 was decreased by 1 from that of S-1.

When comparing the steel-structure model to the RC-structure model having an identical RC slab thickness of 150 mm, the L value of the steel-structure model (S-1) was 55 and the L value of the RC-structure model (RC-1, RC-2) was 54~56, which showed a nearly identical trend in sound insulation performance for both the steel-structure and RC-structure models.

When examining all analytical cases, the L value of the steel-structure model was assessed as 52~55 and

Fig. 5 Framing Plan at 2nd and 3rd Floors of RC-structure Model

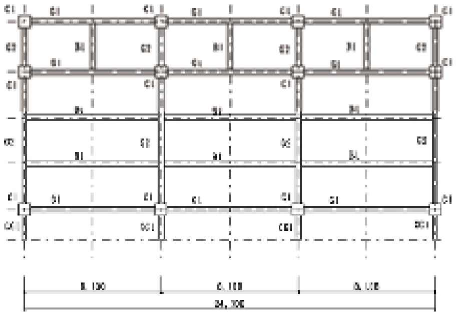


Table 3 Dimensions of Beams and Columns of RC-structure Model

Beam	Section	Sectional area
Girder G1	400×700	—
Girder G2	400×700	—
Beam B1	400×500	—

Column	Section	Sectional area
C1	700×700	—
Foundation footing	1500×1500×1500	

Fig. 6 Specifications of Steel Structure with Deck Plate

"High Deck KHD75" (plate thickness: 1.0 mm)

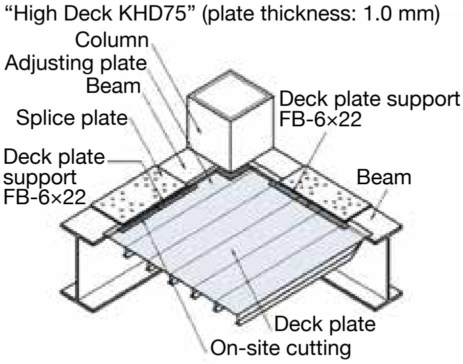


Fig. 7 Plane Condition for Steel-structure Analytical Model

S-1—RC slab thickness: 150 mm; No use of steel form

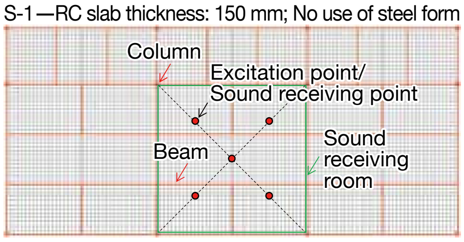


Fig. 8 Analytical Model for Steel-frame Beam and Slab

S-1—RC slab thickness: 150 mm; No use of steel form

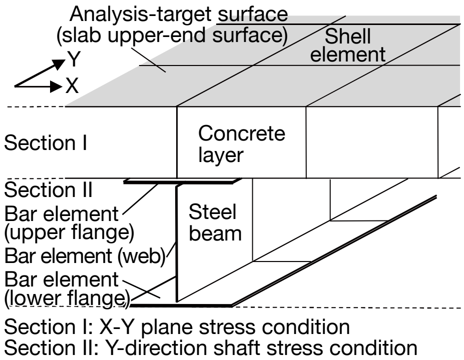


Fig. 9 Vibration Response Distribution of S1

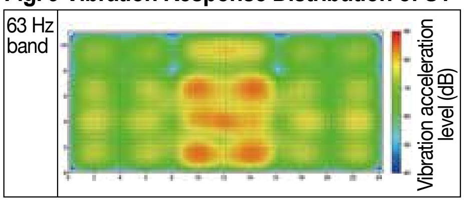


Fig. 10 Vibration Response Distribution of RC-2

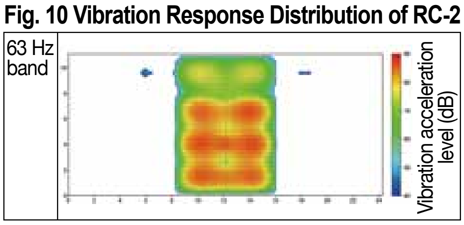


Table 4 Analytical Cases

	Structural type	Classroom dimension (column-to-column span)	Story height	Floor slab	Steel form	Balcony	Partition wall	Indoor sound-absorption condition
S-1	Steel structure	8.1 m × 8.1 m	4 m	RC slab Thickness: 150 mm	No use	No installation	Dry type	Sound reverberation time: 1.0 s (assuming low-sound zone)
S-2				RC slab Thickness: 150 mm	Use Thickness: 1.0 mm			
S-3				Composite slab Deck plate depth: 50 mm + Concrete thickness: 125 mm	Use Thickness: 1.2 mm			
RC-1	RC structure			RC slab Thickness: 150 mm	No use		Dry type	
RC-2							Seismic-resistant wall	

the L value of the RC-structure model was assessed as 54~56. It was confirmed from these assessment results that, while the sound insulation performance changed due to the difference of floor slab type and restriction conditions, no notable difference of the sound insulation-performance between steel structures and RC structures was observed.
(Refer to Table 5 and Fig. 11)

Fig. 11 Analytical Results for Heavyweight Floor Impact Sound Level

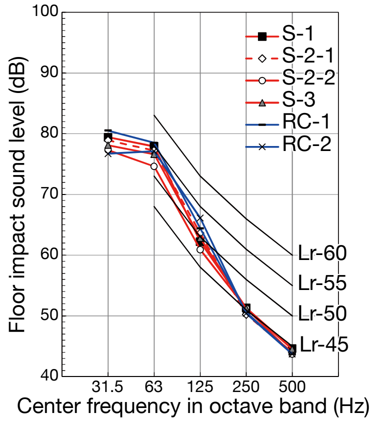


Table 5 Analytical Results for Heavyweight Floor Impact Sound Level (unit: dB)

Model	Center frequency in octave band (Hz)					L value	Slab specification
	31.5	63	125	250	500		
S-1	79.4	77.9	62.2	51.3	44.6	55	RC slab 150 mm
S-2-1	78.9	77.2	63.6	50.2	44.0	54	RC slab 150 mm; use of steel form (no consideration to rib)
S-2-2	77.3	74.6	60.9	51.2	43.7	52	RC slab 150 mm; use of steel form (consideration to rib)
S-3	78.1	76.6	62.8	51.2	44.5	54	Composite slab; concrete thickness: 125 mm
RC-1	80.5	78.5	64.4	50.6	43.7	56	RC slat 150 mm
RC-2	76.7	77.1	66.1	50.4	43.7	54	RC slat 150 mm

Corrected for excitation point number and time weighting characteristics for sound level

Analysis of Walking Vibrations

In order to assess the effect of the difference in structural types (steel structure and RC structure) on the floor vibration-related habitability, the walking vibration was analyzed and examined.

Models Subject to Analysis

The same models as those used in the previous chapter "Heavyweight Floor Impact Sound" were subjected to analysis.

Analytical Conditions

For the approach to analyze the vibration response, the in-plane/out-of-plane coupled-type finite element method shown in the previous chapter was also adopted.

As a condition for walking excitation, a case of walking by one person (specified weight: 60 kg) was assumed. As regards the waveform to input the walking excitation force, it was settled that the waveform per 1 step having 2 peaks at heel collision (Peak P1) and heel landing (Peak P2) was set to repeat a 0.5-second cycle at the walking pace. (Fig. 12).

Fig. 13 shows the walking excitation force input waveform used in the analysis. Fig. 14 shows the plane condition of the steel-structure model used for the analysis.

Fig. 12 Analytical Model for Per-step Walking Excitation Force

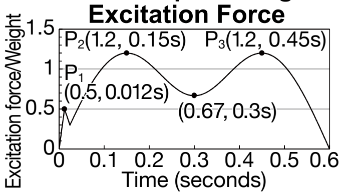
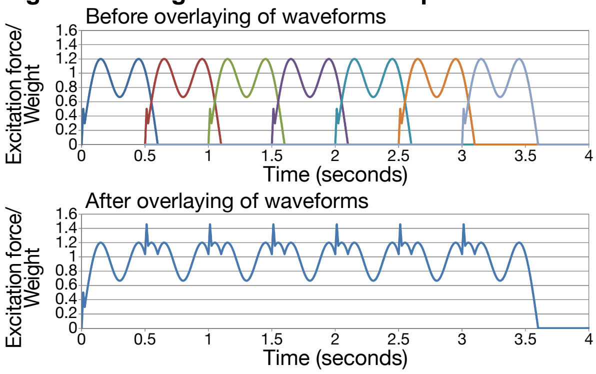


Fig. 13 Walking Excitation Force Input Waveform



Analytical Results

In order to assess the effect of the difference in structural types (steel structure and RC structure) on the floor vibration-related habitability, the floor vibration was analyzed targeting identical building plane plans and using various analytical models in which the difference of the structural type was reflected.

The vibration under the excitation condition assuming one-person walking was analyzed and assessed based on the *Guidelines for the Evaluation of Habitability to Building Vibration* prepared by the Architectural Institute of Japan. As a result, the floor vibration response was assessed at V-10 or lower for both the steel-structure and RC-structure models. (Refer to Figs. 15, 16 and 17)

Fig. 14 Plane Condition of Steel-structure Analytical Model

S-1—RC slab thickness: 150 mm; No use of steel form

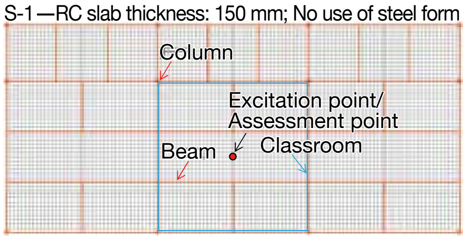


Fig. 15 Analytical Results for Time-history Response Acceleration Waveform due to Walking Excitation

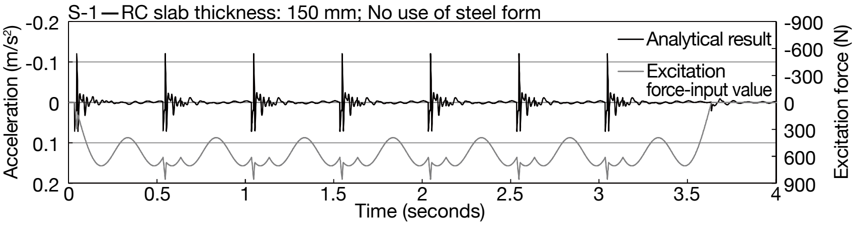


Fig. 16 Analytical Results for Time-history Response Acceleration Waveform due to Walking Excitation

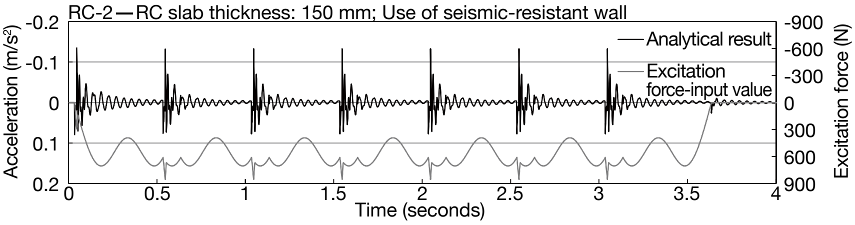
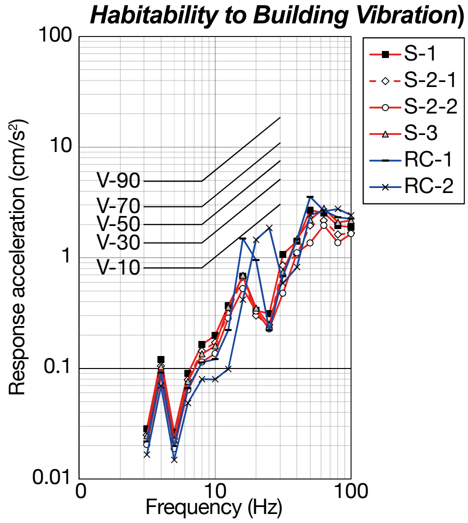


Fig. 17 Assessment Results for Walking Vibrations (AIJ's *Guidelines for the Evaluation of Habitability to Building Vibration*)



Calculation of Annual Thermal Loads

In order to assess the effect of the difference in structural types (steel structure and RC structure) on the thermal environment and air-conditioning load, the thermal load was calculated using the analytical model shown in Fig. 18.

Analytical Approaches and Models

The thermal load was analyzed at an interval of 1 minute and by the use of thermal load analysis software TRNSYS. In the analysis, the indoor heat generation, ventilation and air-conditioning schedule was settled in conformity to the "Calculation and Judgement Methods in Accordance with Energy-saving Standards 2013", and the Expanded AMeDAS Weather Data (2000 edition) was used as the meteorological data.

Analytical Parameters

Table 6 shows the parameters used in the analysis of thermal loads.

Analytical Results for Annual Thermal Load

It was confirmed from analysis that no notable difference of thermal load between the steel-structure and RC-structure models was found thereby demonstrating almost no effect of a difference of structural type on the air-condition load.

Figs. 19 and 20 show the analytical results for annual thermal loads.

Fig. 18 Building Model Used for Thermal Load Analysis

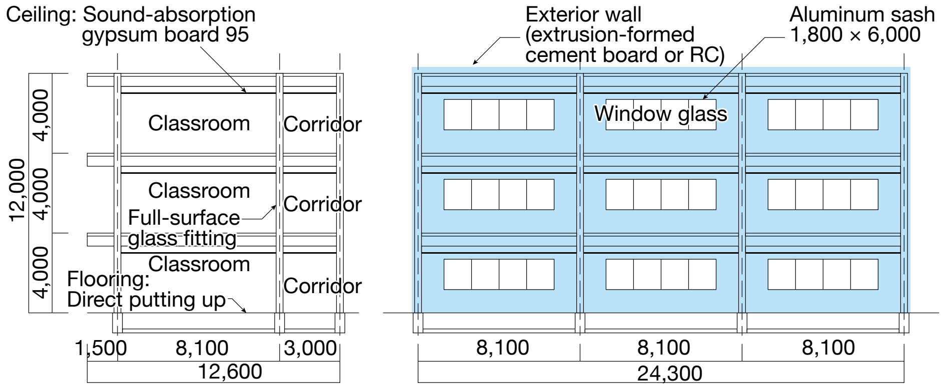


Table 6 Outline of Specifications of Thermal Load Analytical Models

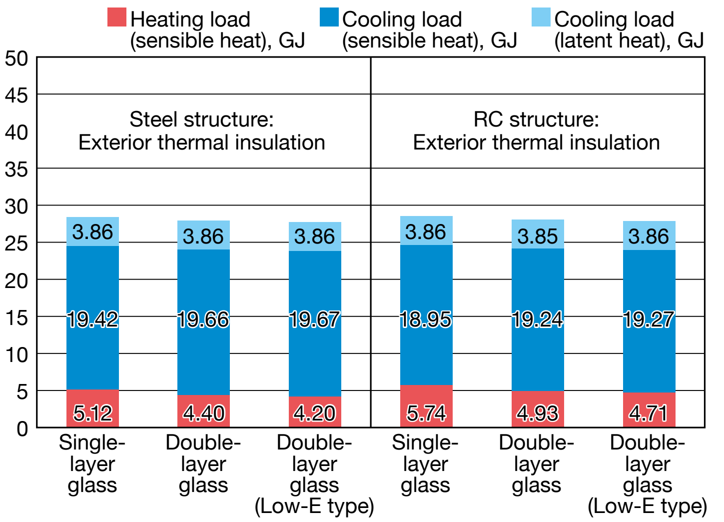
Structural type	Construction site	No. of stories	Story height	Ceiling height	Classroom dimension	Corridor width	Eave, veranda
Steel structure RC structure	Tokyo Sapporo	3	4.0 m	3.0 m	8.1 × 8.1 m	3 m	1.5 m

Structural type	Fire protection	Partition wall (between classrooms)	Exterior wall
Steel structure	No use (impossible to pay consideration)	Dry type Steel stud C-73x45x12x0.8@303 mm Reinforced gypsum board 15 mm + 15 mm (both sides) Basswood plywood 5.5 mm with cloth	Extrusion-formed cement board 60 mm Hard urethane foam 25 mm (Use or no use) *Urethane foam in Sapporo Examination also of 100 mm
RC structure	—	RC (examination only of RC structure) RC thickness: 150 mm Gypsum board 12.5 mm (gypsum lining) Basswood plywood 5.5 mm with cloth	RC thickness: 150 mm Hard urethane foam 25 mm (Use or no use)

Structural type	Outdoor-side window glass	Floor slab	Earthen floor concrete
Steel structure RC structure	Single-layer glass Double-layer glass Double-layer glass (Low-E type) (aluminum sash)	RC 150 mm Flooring: Direct putting up	RC 150 mm Polystyrene foam 25 mm Polystyrene film 0.15 mm

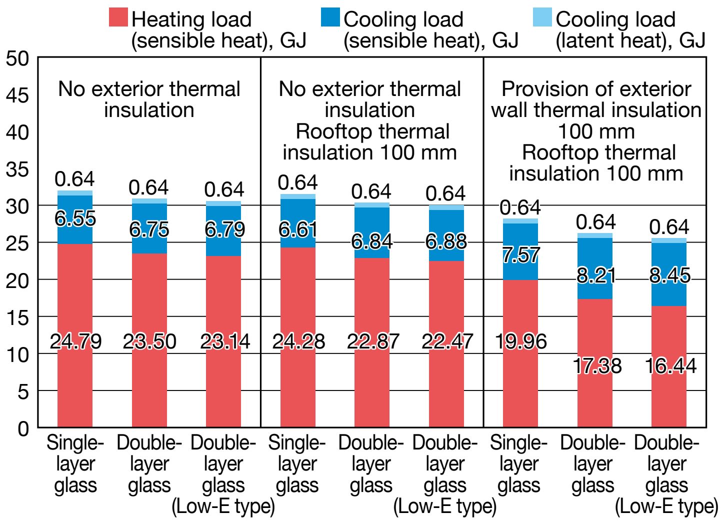
Structural type	Ceiling	Partition (between classroomand corridor)	Rooftop floor
Steel structure RC structure	Sound-absorption gypsum board 9.5 mm	Full-surface glass fitting	Concrete trowel Polystyrene foam 25 mm Composite high-polymer roofing sheet 2.0 mm RC 150 mm

Fig. 19 Comparison of Annual Thermal Load between Steel Structure and RC Structure (Tokyo)



- While the heating load of the steel structure is lower than that of the RC structure, the cooling load of the steel structure is higher than that of the RC structure, and in terms of both heating and cooling loads on an annual basis, no notable difference between two structures was found.
- The difference between heating and cooling loads is considered to be attributable to the effect of the heat capacity of the RC structure.

Fig. 20 Effect of Thermal Insulation Specifications on Thermal Load in Steel Structures (Sapporo)



- The heating load is predominant in cold districts.
- The effect of the difference of opening specifications on the thermal load is high due to reinforced rooftop thermal insulation (from 25 mm to 50 mm).
- The effect of the reinforced thermal insulation (from 25 mm to 50 mm) is higher than that of the difference of opening specifications.

Outstanding Examples in Public Building Construction Employing Steel Structures

Complex Facility—Sukagawa Community Center "tette"

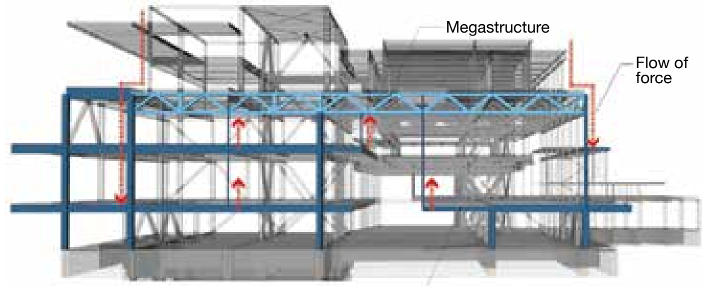
Complex Facility Incorporating Library and Lifelong Study Functions

- Reconstruction project for the comprehensive welfare center damaged by the Great East Japan Earthquake
- Complex facility in which the function as a public hall is integrated with a library and the multiple uses for lifelong study, child care support and a museum are incorporated

♦ Project owner: Sukagawa City, Fukushima Prefecture
♦ Location: Nakamachi, Sukagawa, Fukushima Prefecture.
♦ No. of stories: 5 stories aboveground, 1 basement
♦ Building area: 7,723 m^2
♦ Total floor area: 13,698 m^2
♦ Structural type: Steel structure (partly SRC structure)
♦ Design: Ishimoto Architectural & Engineering Firm and Unemori Architects
♦ Construction: Joint venture of Sumitomo Mitsui Construction and Sanpaku Kougyou
♦ Completion: July 2018

Reasons for the Adoption of Steel Structures

- At the stage of design, a new form of facility was targeted that serves as a new activity site for citizens and as a symbol of reconstruction. The steel structure was suitable for realizing a column-free open space where citizens can gather together and exchange with each other.
- The concept of mega-structure was adopted in order to realize the design that makes many terraces by stacking while setting back the floor.
  —Creation of a space in which columns are not installed on the 1st floor path; Support of the floor using suspension columns and columns installed on the intermediate floor; Formation of a large space structure with a long span of 23.4 m in maximum length and employing cantilever beams with a maximum length of 7.65 m
  In response to these requirements, a steel structure was adopted as a rational structural system that could secure sufficient rigidity and strength required to support the upper and lower floors.



Structural Diagram

School—Shiota Junior High School

Y-shaped Steel-frame Unit to Harmonize with Surrounding Areas and to Provide Flood Measure

- Adoption of a gambrel roof that harmonizes with the landscape peculiar to an old post town
- Raised-floor structure (installation of steel-frame underground beam on the pile top retained at a high position)

♦ Project owner: Ureshino City, Saga Prefecture
♦ Location: Shiotacho, Ureshino City, Saga Prefecture
♦ No. of stories: 2 stories aboveground
♦ Building area: 7,660 m^2
♦ Total floor area: 8,436 m^2
♦ Structural type: Steel structure
♦ Design: Suemitsu Hirokazu+Suemitsu Yoko/SUEP+Sasaki Nobuaki/INTERMEDIA
♦ Construction: Toa Corporation
♦ Completion: August 2014

Reasons for the Adoption of Steel Structures

- Lightweight construction (the site is located in a sandbank with weak ground, and it was required to adopt a raised-floor structure as a flood countermeasure.)
- Creation of open space
- Sense of security imparted by the steel structure
- Cost reduction

School—Kamaishi-Higashi Junior High School, Unosumai Primary School, Unosumai Child Hall

Reconstruction Symbol Built on High Land in a Disaster-stricken Area

- Reconstruction plan for a primary school, junior high school, child hall and kindergarten damaged by the Great East Japan Earthquake
- Restriction of earth drilling volume of the mountain area that serves as a building site to a minimum level and development of the land for a building site while retaining the mountain ridge by working out an integrated civil engineering/building construction plan so as to suppress the construction cost and term

♦ Project owner: Kamaishi City, Iwate Prefecture
♦ Location: Unosumaimachi, Kamaishi City, Iwate Prefecture
♦ No. of stories: 4 stories aboveground
♦ Building area: 6,309 m^2 (total of primary school, junior high school, child hall)
♦ Total floor area: 11,142 m^2 (total of primary school, junior high school, child hall)
♦ Structural type: Steel structure
♦ Design: Kojima Kazuhiko+Akamatsu Kazuko/CAt
♦ Construction: Joint venture of Obayashi, Kumagai Gumi, Toyo Construction and Motomochi Group
♦ Completion: March 2017

Reasons for the Adoption of Steel Structures

- Selection of a steel structure by taking into account the construction cost and term, and ground conditions
- In the adoption of the steel structure in the "birthplace of the modern steel industry, KAMAISHI," the building design was made by raising awareness of the positive expression of steel-frame members, which has improved the image of steel frames and led to cost reduction.

Photo: Masao Nishikawa Photography Studio

School—Bantani Primary School

Harmony with the Natural Environment, Flexibly Expanding School Environment

- Adoption of timber as an interior member
- Ordinary classroom that allows flexible applications using movable partitions

♦ Project owner: Koka City, Shiga Prefecture
♦ Location: Minakuchicho, Koka City, Shiga Prefecture
♦ No. of stories: 3 stories aboveground
♦ Building area: 3,344 m^2 (school building)
♦ Total floor area: 6,251 m^2 (school building)
♦ Structural type: Steel structure
♦ Design: Katabuchi Architects
♦ Construction: Joint venture of Toda and Nishimura Construction
♦ Completion: March 2003

Reasons for the Adoption of Steel Structures

- Lightweight construction of the building (suitable for the construction at the developed ground)
- Reduction of surplus soil excavation due to the reduced pile foundation work (environmental considerations)
- Construction term reduction (by about 2 months from RC construction)
- Availability of large-span space and ease of change in indoor layout
- Flexible response to future enlargement and reconstruction
- Recyclability of steel members in the event of demolition

Government Office—Yamaga City Government Office Building and Yamaga Citizens' Exchange Center

Efficient and Functional Government Office Building that is Human- and Eco-friendly

- The rebuilding of the superannuated government office building for the new Yamaga City inaugurated by the merger of 1 city and 4 towns in 2005; Due consideration paid to ease-of-understanding and use by intensively arranging the help desk to low-rise floors; Rebuilding plan for a town building that allows for citizens to easily gather together through the provision of a spacious public hall, meeting place and library attached to the government office building
- For use as a disaster-prevention base, adoption of a base-isolation structure for the government office building, diversification of heat sources and installation of a power generator to allow continuous operation for about 72 hours, and a water tank and sewage storage tank to allow water supply for 7 days
- Design that takes into account improved maintenance and comfortability such as energy saving measures by the use of solar power generation, rainwater, optical ducts and other natural resources and reduced solar light burdens with the optimum use of eaves

♦ Project owner: Yamaga City, Kumamoto Prefecture
♦ Location: Yamaga, Yamaga City, Kumamoto Prefecture
♦ Design: Kume Sekkei
♦ Construction: Obayashi Corporation
♦ Completion: September 2014 (main building)

Government office building
♦ No. of stories: 5 stories aboveground, 1 basement
♦ Building area: 2,376 m^2

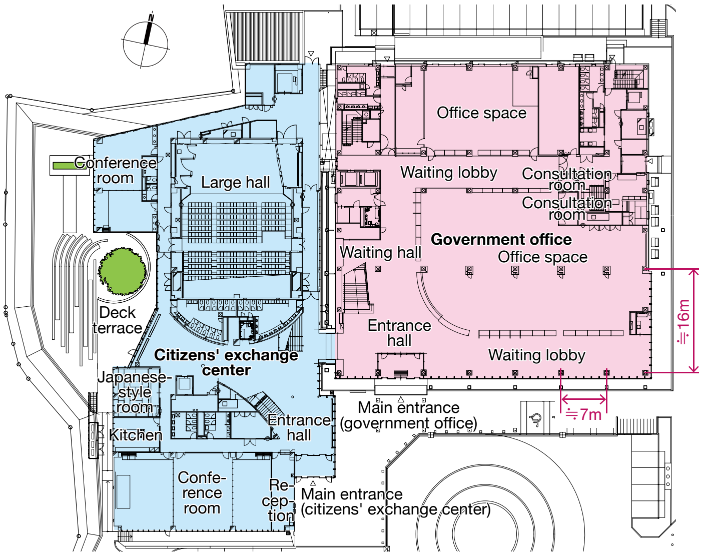

Photo: SS Co., Ltd.

♦ Total floor area: 9,341 m^2
♦ Structural type: Steel structure (partly SRC structure); Base-isolation structure

Citizens' exchange center
♦ No. of stories: 2 stories aboveground, 1 basement
♦ Building area: 2,154 m^2
♦ Total floor area: 2,894 m^2
♦ Structural type: SRC structure (partly steel structure); Seismic-resistant structure

Reasons for the Adoption of Steel Structures

- Reduced construction term, and decreased number in the use of both base-isolation devices and foundation piles due to long-span construction
- Decreased number in the use of base-isolation devices and reduced size of piles by means of lightweight construction
- Adoption of a steel-RC composite structure for the basement and concrete-filled steel tube columns in order to secure the stiffness required for a base-isolation building



Government Office—New Saijo City Government Office Building

Eco-friendly Building Constructed by the Optimized Use of Features Unique to the Locale

- Use of locally-produced timber as interior members and exterior wall members
- Securement of natural ventilation by the use of ascending air current and prevailing wind inside the stair tower

♦ Project owner: Saijo City, Ehime Prefecture
♦ Location: Akeyashiki, Saijo City, Ehime Prefecture
♦ No. of stories: 7 stories aboveground
♦ Building area: 1,483 m^2
♦ Total floor area: 9,448 m^2
♦ Structural type: Steel structure
♦ Design: Yasui Architects & Engineers
♦ Construction: Joint venture of Nishimatsu Construction, Shiraishi Construction Industry and Yumiyama Kensetsu
♦ Completion: January 2014

Photo: KOKUSAIKIKAKU

Reasons for the Adoption of Steel Structures

- Realization of column-free business space
- Decreased number in the installation of isolation devices by means of lightweight building construction
- Reduction of construction term

Hospital—Ibaraki Western Medical Center

New Hospital to Take Responsibility for Acute-phase Medical Care in the Western Area of Ibaraki Prefecture

- Reorganization project for integrating 3 hospitals— the public Chikusei Citizen Hospital and Kensei General Hospital, and the private Sanno Hospital
- Based on the experience in which former hospitals suffered from the Great East Japan Earthquake, an ECI system* was adopted so as to respond to pressing tasks for realizing hospitals that serve as a disaster-prevention base and have base-isolation functions

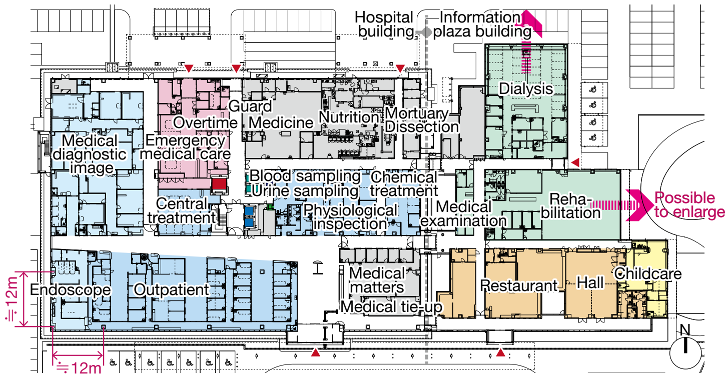
*ECI (early contractor involvement) system: The general contractor participates in the project from the stage of design and extends technical cooperation in design thereby offering expectations for reduced construction cost and term.

♦ Project owner: Chikusei City, Ibaraki Prefecture
♦ Construction site: Otsuka, Chikusei City, Ibaraki Prefecture
♦ No. of stories: 6 stories aboveground (hospital building); 1 story aboveground (information plaza building)

♦ Building area: 8,688 m²
♦ Total floor area: 19,394 m²
♦ Structural type: Steel structure (base-isolated hospital building): Steel structure (seismic-resistant information plaza building)
♦ Design: YAMASHITA･NEMOTOHIDE SEKKEI JV
♦ Construction: Maeda Corporation
♦ Completion: August 2018

Reasons for the Adoption of Steel Structures

- Adoption of long-span framing to enhance the freedom in working out the inside plan for the hospital building
- Decreased number in the installation of base-isolation devices due to long-span framing and assessment of the steel structure as a rational structure in terms of cost



Hospital—Chutoen General Medical Center

LCB Hospital Constructed by the Integration of Kakegawa and Fukuroi City Hospitals

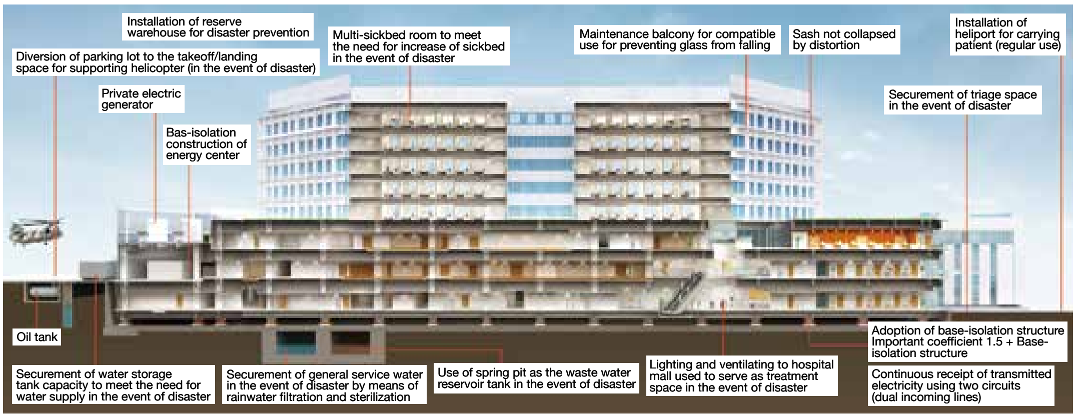
- Design of a hospital building considering the continuity of medical function (life continuity building or LCB) because of the location in the epicenter of forecast Tokai Earthquake

♦ Project owner: Kakegawa City-Fukuroi City enterprise consortium, Shizuoka Prefecture
♦ Construction site: Shobugaike, Kakegawa City, Shizuoka Prefecture
♦ No. of stories: 8 stories aboveground
♦ Building area: 11,804 m²
♦ Total floor area: 44,529 m² (500 sickbeds, possible to increase to 825 sickbeds)
♦ Structural type: Steel structure (base-isolation structure)
♦ Design: Kume Sekkei
♦ Construction: Joint venture of Obayashi, Tozka and Marumei
♦ Completion: March 2013

Reasons for the Adoption of Steel Structures

- High freedom that can meet diverse architectural requirements—Less restrictions imposed on the angle on which a beam attaches to a column; Securement of column-free open space
- High flexibility that can meet future change of functions and enlargement—Decreased number in the installation of columns by means of long span construction; Shortening of beam depth and securement of a ceiling space required to provide piping routes; High freedom in the arrangement of the holes that penetrate the beam for piping
- Reduction of construction term and environmental impact—Reduction of construction term due to labor-saving work at site by factory fabrication of building frame; Reduction of noise and vibration in the surrounding environment through labor saving and rationalization of on-site work

Photo: SS Co., Ltd.



Shibuya Station on the Tokyo Metro Ginza Line

—Column-free Subway Station Building Constructed by the Use of 45 Continuously-arranged M-shaped Steel Arches—

Naito Architect & Associates
KAP

A large-scale urban redevelopment project is being promoted at Shibuya, in downtown Tokyo. In connection with this redevelopment project, Shibuya Station on the Tokyo Metro Ginza Line, located aboveground, was relocated eastward by about 130 m, and a new subway station building covered with aluminum panels and glass was constructed spanning Meijidori Avenue. M-shaped steel-frame arches were adopted for the construction of the station building roof. A total of 45 M-shaped arches were continuously aligned at an interval of 2.5 m, which brings about a column-free spacious platform with a total extension of 110 m. (See Photo 1)

With many restrictions that had been imposed on the building plan, how was the M-shaped arch realized? Those engaged in the structural design of the Shibuya Station tell about the relocation project successfully completed capitalizing on the application of the M-shaped arches and newly-devised construction technologies peculiar to railway operations.

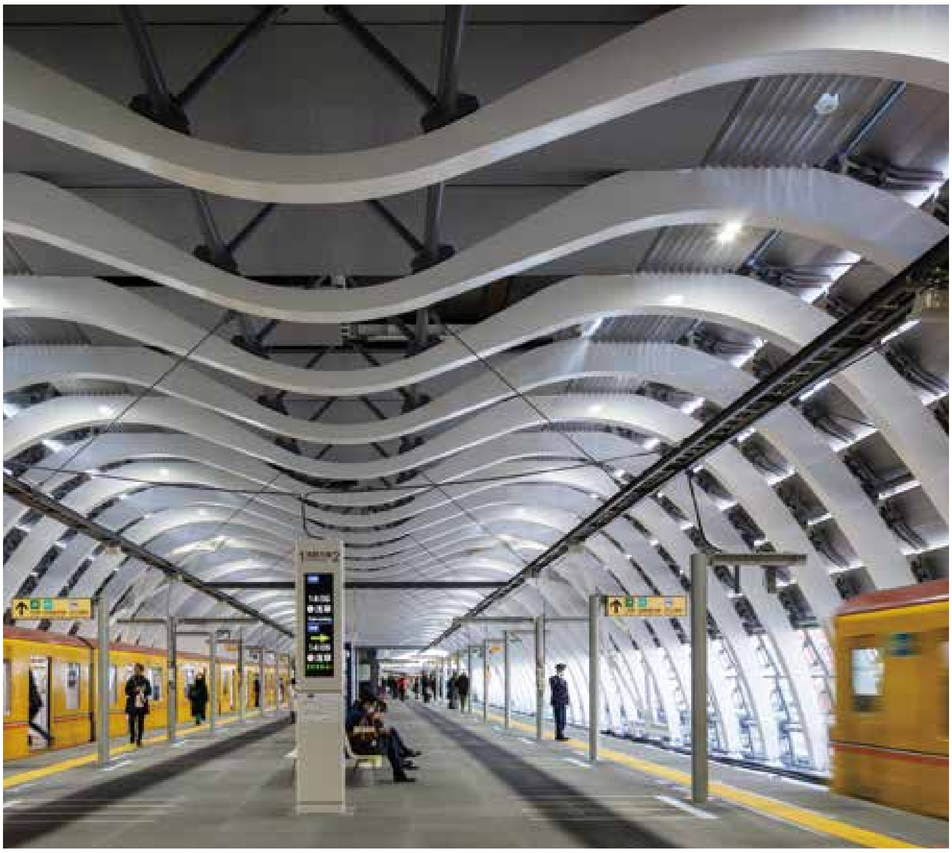


Photo 1 Spacious platform at Shibuya Station on the Tokyo Metro Ginza Line, which was realized capitalizing on M-shaped steel arch framing

Relocation of Shibuya Station on the Ginza Line

We think it was probably around 2009 that we heard about the relocation project of Shibuya Station on the Tokyo Metro Ginza Line. The urban redevelopment project at Shibuya had started due to the ongoing superannuation of many buildings located around Shibuya Station and the resultant need to reconstruct related infrastructure facilities. Among these reconstruction projects was the rebuilding plan around the Shibuya Station East Exit Square, where two relocation projects were examined—an overpass (pedestrian deck at the East Gate of Shibuya Station, completed in 2012) that connects the Shibuya Hikarie (complex facility building) and the East Exit of JR (Japanese Railway) Shibuya Station and Shibuya Station on the Tokyo Metro Ginza Line.

Shibuya Station on the Tokyo Metro Ginza Line is a terminal station. Although the Ginza Line is a subway line, the platform of Shibuya Station is located aboveground because the site around Shibuya Station is composed of a valley-shaped topography.

In the current urban redevelopment project, it was decided that the platform of Shibuya Station on the Tokyo Metro Ginza Line be relocated eastward by about 130 m partially spanning Meijidori Avenue, and that the relocated Shibuya Station be reconstructed as a key facility that connects JR Shibuya Station, Shibuya Scramble Square and Shibuya Hikarie.

Further, in the building plan for the peripheral area, it was decided that, as with the overpass mentioned above, steel girders be erected spanning Meijidori Avenue by 55 m, on which the subway runs, and that a pedestrian deck called Skyway be constructed further on the railway line to connect Dogenzaka (westside area of Shibuya Station) and Miyamasuzaka (eastside area).

(Refer to Photo 2 and Fig. 1)

Examination of Configuration of the Station Building

The new station building of Shibuya Station on the Tokyo Metro Ginza Line is an over-track station constructed spanning

Meijdori Avenue and the East Exit Square, and its total length measures about 110 m. The platform in the former station was two separate platforms servicing two tracks, and its width was a narrow 6 m. In contrast, the platform on the new station is an island platform serving two tracks, and its width has been broadened to up to 12 m.

The periphery of the East Exit Square is crowded with many buildings, and thus not much of the sky can be seen. In order to visually suppress the voluminous impression of the station building, the sectional form was designed with a configuration in which the corner section was shaved off, rather than a square configuration. On the condition of placing the pedestrian deck on the building, further examinations were made of the building structure. For the upper structure of the station building, because the subway runs, it was impossible to erect columns inside the building. To that end, arch framing was adopted for the construction of the upper structure of the station as it straddles the platform. (Refer to Figs. 2 and 3)

Among other restrictions imposed on the relocation project was "structural clearances" such as the dimensional clearance imposed on the location of the structures in the space above the track. Another restriction was to proceed with the project while regularly operating the subway line, and thus it was required to provide certain room in the height of the frames to be applied to the upper section of the station building. Further, it was planned to install a pedestrian deck (Skyway) on the station building. For the pedestrian deck, the installation level at both the Miyamasuzaka side and the JR Shibuya Station was already designated, and thus the gradient of the pedestrian deck was also designated. Needless to say, the gradient of the subway track was also designated. In short, the upper and lower heights at the respective project sites had already been designated.

In terms of the plane of the station building, the track configuration was designated. While nobody pays much attention to the detailed track configuration, the track at one side shows curving when looking from the Miyamasuzaka side, then the track runs straight in the midway, and finally it slightly expands in the railway siding area. In this way, the track height shows changes in terms of not only plane but also section. We felt as if we were surrounded by diverse kinds of restrictions occurring both inside and outside of the station building. Because the height and width of the track in the project site changed in three-dimensions, complex work was needed to be implemented in the current relocation project. (Fig. 4)

The restrictions were imposed in the course of project promotion. It was required to proceed with the construction of the station building without not only the traffic close on Meijidori Avenue but also the suspension of subway traffic. It was also necessary for the project to be promoted by repeating changeovers of tracks and changing the level of the track.

Photo 2 East Exit Square at Shibuya Station and the new station building being constructed spanning Meijidori Av.

Fig. 1 Location of Facilities around Shibuya Station

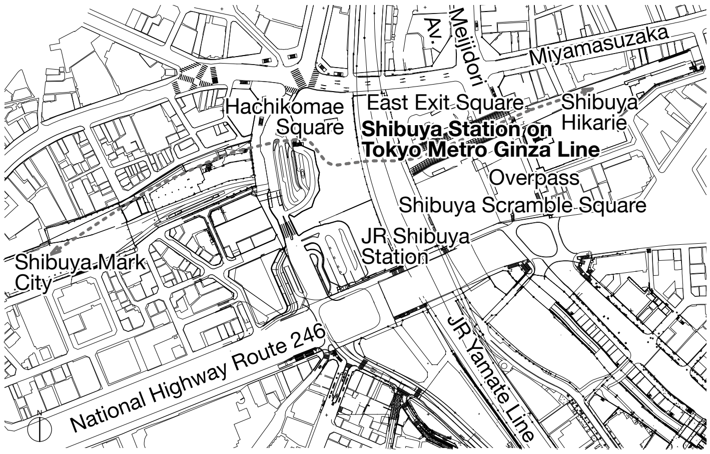


Fig. 2 Plane of Shibuya Station on the Tokyo Metro Ginza Line (completion stage)

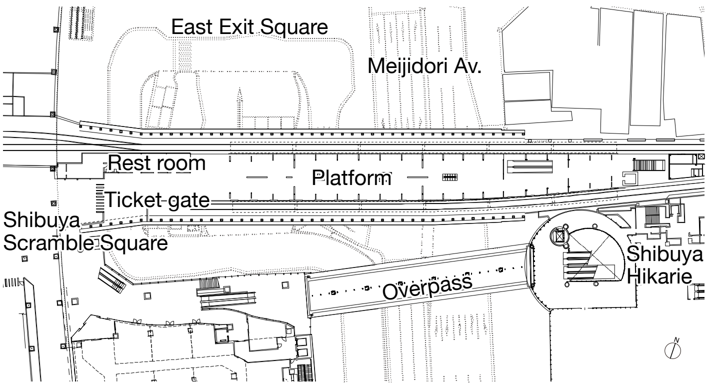


Fig. 3 Longitudinal-direction Section of Shibuya Station on the Tokyo Metro Ginza Line

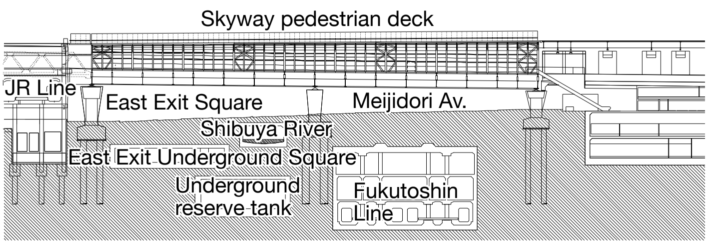
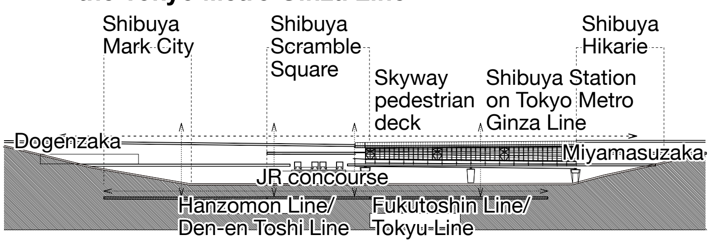


Fig. 4 Wide-section Diagram around Shibuya Station on the Tokyo Metro Ginza Line



Curved Beams Composed of M-shaped Steel Frames

Regarding the building framing, we examined the adoption of semi-circular arch framing at the initial stage of design. However, if this type of framing were adopted, the contact section with the pedestrian deck would become narrow and the framing would be unstable in order to securely bear the deck's large load. Then we proposed a rational arch design that can easily bear the deck load: Specifically, the structural height is provided to the position where the deck is placed. That is, the center section of the arch framing is shaped convex downward, and the M-shaped arch framing is structured in which the convex arch framing and upper deck structure are integrated. (Refer to Figs. 5 and 6)

When this M-shaped arch design was proposed, we thought this design was just right. The organic configuration produced by continuously arranging M-shaped framings is so interesting, and the letter M of the M-shaped framing associates with the corporate mark M of the Tokyo Metro. To that end, we thought this proposition would be accepted by Tokyo Metro Co., Ltd. without dissent. As expected, Tokyo Metro raised no objection to the M-shaped framing design.

The M-shaped arch is a steel-frame member with a height of 6.7~8.5 m and a width of 20.5~25.2 m. Even after designation of the arch configuration to an M-shape, examinations were implemented of the arch erection interval and other details employing study mockups. Finally, it was decided that a total of 45 M-shaped steel arch members would be erected at an interval of 2.5 m to structure the entire roof framing.

The steel product adopted for the M-shaped arch was SN490B (rolled steels for building structures). A feature of this M-shaped arch is the box-shaped curved beam. The sectional dimension is 300 mm in width for all arch members, but the height varies. While the depth is high for the section where the bending moment is dynamically high, the depth is reduced for the lower end of the M-shaped arch because it serves as the pin. The center section of the arch cannot be formed only by the use of an M-shaped beam, and therefore the truss was assembled by the combined use of beams at the side of the floor slab that is placed on the arch and the downward convex section at the center section of the M-shaped arch. Accordingly, the section of M-shaped arch became smaller.

In other words, while making full use of the curved configuration of the M-shaped arch and adding sectional devices, an arch configuration with less useless structural sections was realized. Although we simply say "less useless structural section," it would be easy for the fabricating side to manufacture structural members with identical sections, but we asked the fabricating side to do their best in order to realize "less useless structural sections."

In the initial stage of design, the topic was brought up as to whether the arch framing with a configuration shown in the bending moment drawing could be manufactured. It would be possible to manufacture such a framing with the use of thick structural members. However, while being theoretical, we adopted the above-mentioned M-shaped arch by taking into account the dynamic aspect required for the roof framing. (Fig. 7)

Adoption of Sliding Method in the Erection of Steel Framings

In the current relocation project, because the station building was to be constructed while securing both Meijidori Avenue traffic and

Fig. 5 South-North Section of the Platform at Shibuya Station on the Tokyo Metro Ginza Line (Meijidori Av. Side)

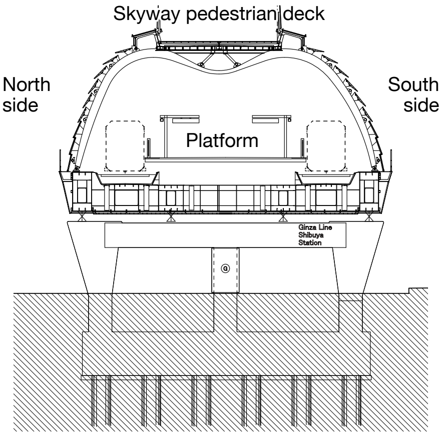


Fig. 6 South-North Section of the Platform at Shibuya Station on the Tokyo Metro Ginza Line (Station Square Side)

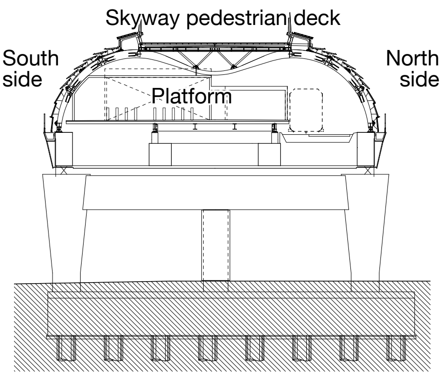
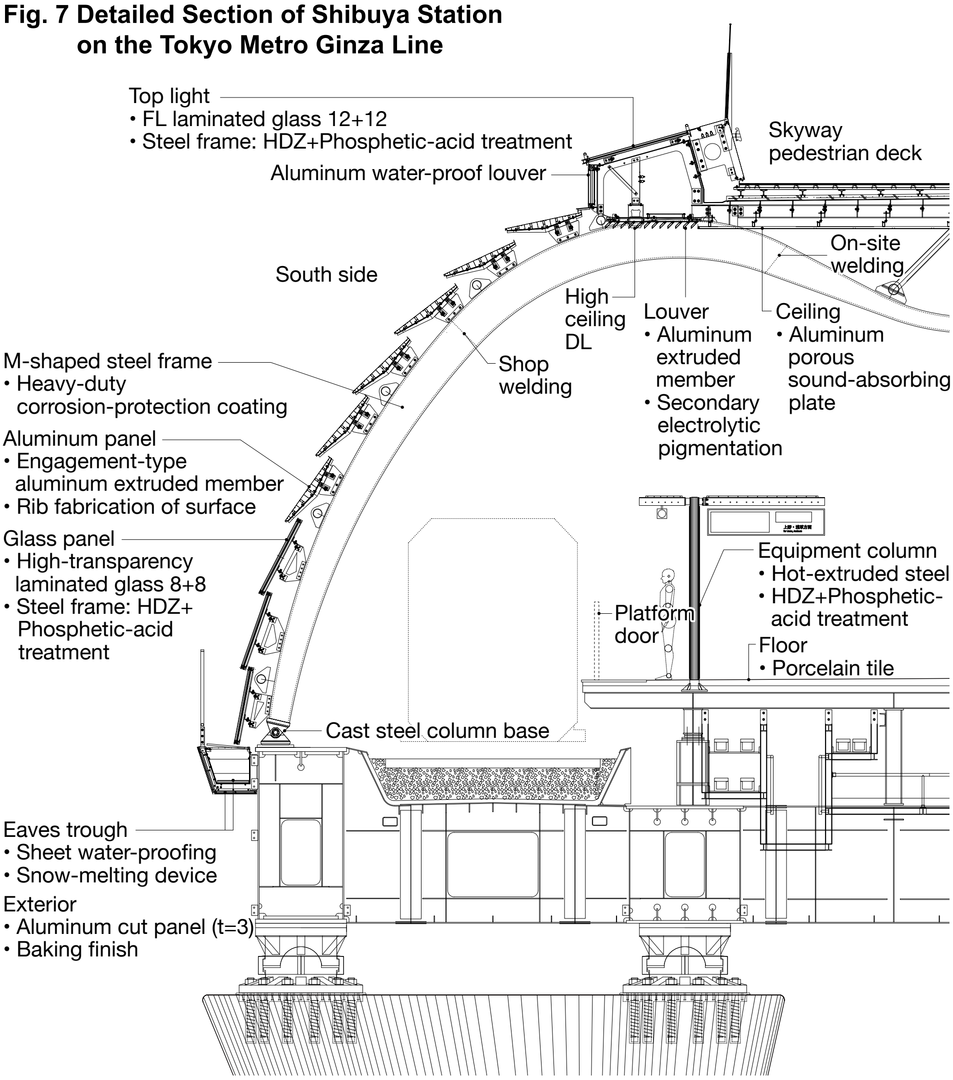


Fig. 7 Detailed Section of Shibuya Station on the Tokyo Metro Ginza Line



regular subway operations, the site for installing cranes was restricted. To cope with such a situation, the sliding erection method was adopted in which the temporary bent was installed as it straddles the track, the M-shaped arch framing was assembled by means of on-site welding on the bent, and then the assembled framing was moved to the specified erection position. This sliding method was truly an excellent technology. Its detailed process is as follows:

At first, eight spans of arches to be erected at the Shibuya Hikarie side of the track were assembled on the bent, which were slid to the Hikarie side. Then three spans of arches were assembled on the bent and pushed to the JR Shibuya Station side, and this was then repeated to cover the remaining 70 m-long platform section. The largest arch weighed 820 tons, which was moved by 15.5 m. Lastly, arches on the bent were assembled to complete the erection of the M-shaped arches on the platform. A total of 45 M-shaped arches were erected over about one year. (Refer to Photo 3 and Fig. 8)

Tomoe Corporation in charge of the erection work has handled many special building construction projects, and thus the company accurately prepared work plans to steadily proceed such a difficult project. We surely felt the high skill offered by the Japanese steel-frame fabricators. In addition, Tokyu Construction Co., Ltd. in charge of the entire project management extended joint support in tackling this difficult project. (Photo 4)

Erection of Unbond Braces at Four Longitudinal-direction Sections

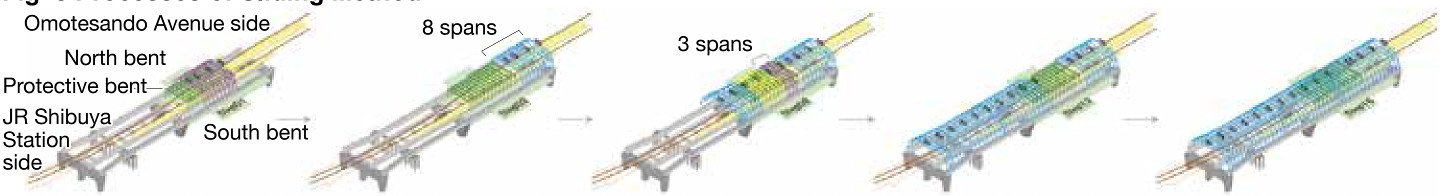
In order to secure seismic resistance, the arch structure was securely anchored underground for the transverse-direction section of the framing. But for the longitudinal-direction section of the building framing, it was considered to be better to basically adopt simple construction, and thus small-section beams were adopted. In compensation for this, "unbond braces" (buckling-restraint braces) were arranged in four sections of the building framing to handle seismic forces. (Refer to Fig. 9)

After finishing the execution design and the start of construction, in order to secure the moving line at the stage of resuming operations, the project owner made a request to install a passage where people could pass between frames to which unbond braces are arranged.

Regarding the section in which unbond braces were removed, as a result of various examinations, the framing around the opening was reinforced to maintain seismic resistance. It was helpful that the frame was originally designed as one featuring structural redundancy and margins, and as a result we could clear the request without any reduction of structural strength and by means of reinforcing beams and increasing the plate thickness of frames while balancing the structural strength of the entire framing structure. We could successfully meet the owner's request because of the application of steel structures, but if other structures had been adopted, it would have been difficult.

On the Ginza Line, the changeover of the track at Shibuya Station was carried out by restricting subway operation to Omotesando Station, one stop before Shibuya Station, during six days from De-

Fig. 8 Processes of Sliding Method



The M-shaped steel-frame arch is assembled on the protective bent installed as it straddles the track.

Eight spans of arches are slid to the Omotesando Avenue side. Before sliding, the exterior panel and glass panel are attached to the M-shaped arch.

M-shaped arch assembled on the bent is slid to the JR Shibuya Station side basically by three spans, and this process is then repeated.

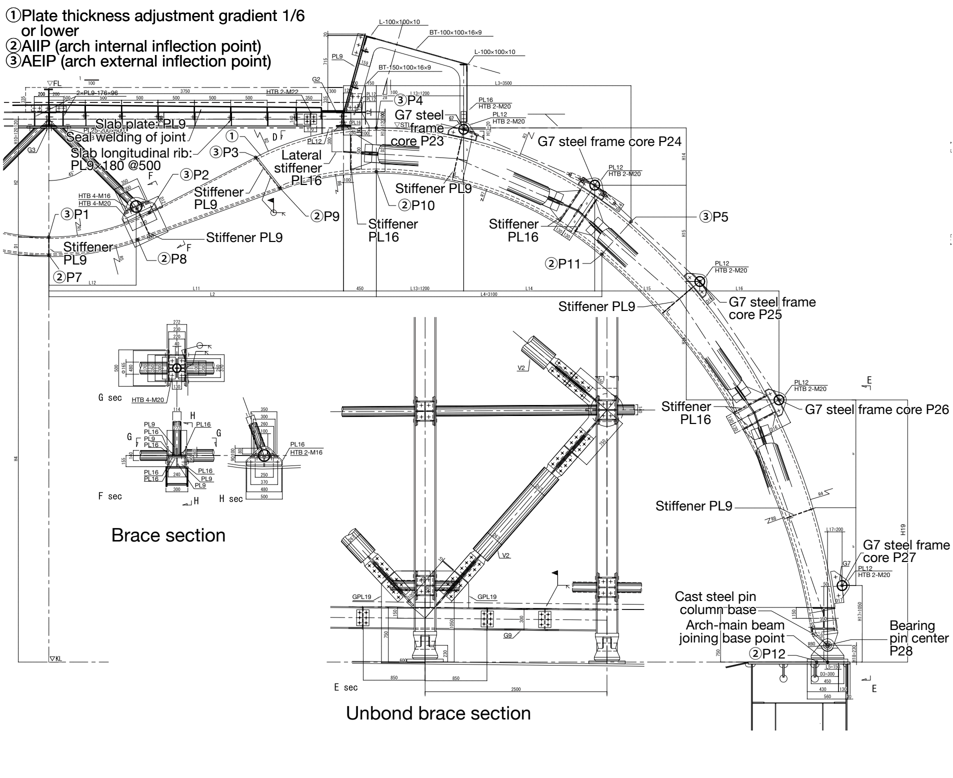
After sliding, M-shaped arch is fixed to the pedestal by means of jacking down and then welding.

Lastly, the M-shaped arch on the bent is assembled. An entire span of arches was assembled in 10 months while regularly operating the train.

Photo 3 M-shaped arch divided into three members is carried into the construction site, which is on-site weld-joined by welding workers.

Photo 4 All those involved in M-shape frame fabrication at the Oyama Plant of Tomoe Corporation gathered together to confirm the mockup and make final adjustments.

Fig. 9 Details of M-shaped Arch and Brace Section



cember 28, 2019, to January 2 of the following year. During these six days, a total of 5,000 workers participated in the track changeover. We happened to be present at the work site and were overwhelmed by the large and complex scale of the work.

While we observed the track changeover work from the command room where monitor TVs were set up, on-site workers attached pin cameras on their helmets, and when the command room instructed "No. 2 worker! Please reflect this side," the instructed image of that side was projected on the monitor TV. After finishing the round-the-clock work over six days, the new Shibuya Station on the Tokyo Metro Ginza Line resumed its regular service with the departure of its first train on January 3, 2020.

Exact Assessment of Excellent Technologies

In the design of special buildings requiring difficult structural work such as the station building introduced above, the first task is to search for an appropriate company from among many steel-frame fabricators. While there were many fabricators with special and advanced technologies, regrettably there were cases in which some of these fabricators had not kept going. In cases when the cost that offsets the special technology is not accepted, we think that the level of technological capability of Japanese fabricators will follow to decline. We consider it necessary to establish the concept that "advanced technology naturally requires proper cost."

In the current relocation project, many technical experts extended their cooperation. This has helped us to understand the important theme of how many such excellent experts can be secured in the future, too. How many experts will continue to exist around us in the future—especially those having high technical expertise vis-à-vis such fields as welding technology and the accurate sliding control of steel frames? This seems deeply involved in the future development of steel-structure culture. Without such experts in the future, projects such as this one will not be feasible. The reason why we, architects, can challenge the task of difficult projects is attributable to the fact that these technical experts are ready to extend their full support.

Outline of Shibuya Station on the Tokyo Metro Ginza Line

Location	Shibuya, Shibuya-ku, Tokyo
Project owner	Tokyo Metro Co., Ltd.
Main application	Railway facility
Area	Site area: 9,899.42 m^2 Building area: 2,662.80 m^2 Total floor area: 5,212.52 m^2
Structure	Main building Steel structure
No. of story	2 stories aboveground, 2-story basement
Maximum height	20,000 mm
Design	Architecture Naito Architect & Associates Metro Development Co., Ltd. Tokyu Architects & Engineers Inc. Structure: KAP Equipment: P.T. Morimura & Associates, Ltd.
Construction	Joint venture of Tokyu Construction Co., Ltd., Shimizu Corporation and Kajima Corporation
Design term	October 2015~June 2016
Construction term	August 2018~December 2019
Photo courtesy of	Makoto Yoshida of *Nikkei Architecture* and Naito Architect & Associates

Photo 5 Full view of the platform at Shibuya Station on the Tokyo Metro Ginza Line. Advanced steel construction technologies were fully applied in the station relocation project.

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