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【 s u - m u 】

"住む (*su-mu*)" in Japanese, or "live" in English

After choosing a house and its location, people live there; Living

Steel structures are increasingly being used as houses, station buildings and other structures common to our daily life.

In this issue.....

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Conservation and Restoration of Tokyo Station Building

by Atsushi Hayashi, Manager, Structural Engineering Center, Construction Dept., East Japan Railway Company; and Katsuhiko Osako, Deputy Director, Design Div., JR East Design Corporation

Located in Marunouchi at the center of Tokyo, the Tokyo Station Building is familiarly known as the "Red-brick Station Building" in Japan. Designed by Kingo Tatsuno, the father of modern architecture in Japan, the building opened in 1914. While damage to its roof and exterior walls caused by air raids during the Second World War led to the building being lowered from its original three-story construction to two stories, the station has long served as Tokyo's main railway station and is representative of Japanese buildings erected in the Taisho and Showa Eras (together spanning most of the 20th century). (Photos 1 and 2)

With this background, the Tokyo Station Building was designated as an Important Cultural Property of Japan in 2003. In 2007, a project was begun to conserve as much of the existing station building as possible while restoring it to its original appearance. The project was successfully completed in October 2012.

History and Structure of Tokyo Station Building

● Appearance of Original Building

Facing the Imperial Palace, the Tokyo Station Building is a long structure with a total length of 335 m. As it originally stood, the building had three stories above ground and one that was partially underground; it also had a one-story annex building at its rear (station platform side). The total floor area was 10,500 m^2.

Photo 2 Damage by air raids

● Steel-frame Building Structure

The framing structure, shown in Fig. 1, was adopted for construction of the station building. Ten-inch I-beams were adopted for most of the columns.

The steel frames used for each structural section weighed a total of 3,135 tons. The adopted building plan called for the use of as many domestically produced steel products as possible. The steel products supplied by overseas producers were used for the columns and joining members that would get much usage, and those produced at the government-run Yawata Steel Works in Japan were used for all the other structural members. Domestic steel products accounted for 56% of all the steel products used, and the foreign steel products for 44%. The major suppliers of foreign steel products were Carnegie Steel Company of the U.S. and Frodingham Iron & Steel of the U.K.

Manufacture and assembly of the steel frames started in September 1909, and installation of all the steel-frame members was finished in September 1911 (Photo 3).

On-site surveys of the Tokyo Station Building conducted in 1988 found localized structural deterioration and various structural concerns, but indicated that the building had been kept in good condition as a steel-frame/masonry structure even 75 years after construction.

Fig. 1 Wall Framing[1)]

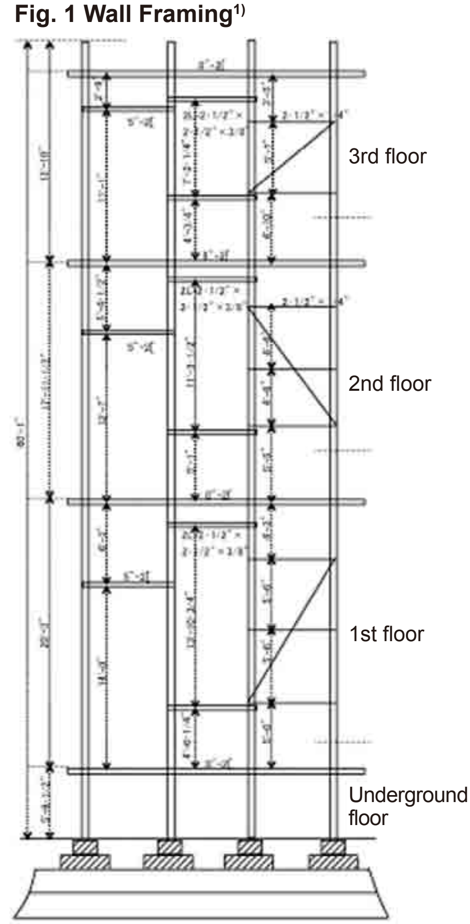


Photo 1 Appearance of Tokyo Station Building in the days of initial construction (1914)

Restoration of the Historical Station Building

The primary objective of the restoration work was to provide sufficient seismic resistance. The restoration design was made so that, even in the event of the largest predictable class of earthquake, cracking in the brick walls would be allowed but the building itself would be used without the need of any large-scale repair work.

Extensive examination of seismic resistance showed the following results: with adoption of the base-isolation method, almost no seismic reinforcement would be required. On the other hand, if conventional seismic reinforcing methods were employed, about half of the interior walls would need reinforcement. Consequently, it was decided to adopt the base-isolation method in view of the projected improvements to structural safety, application freedom and conservation accuracy. (Photo 4)

Renewed Historical Building

Conservation and restoration of the historical Tokyo Station Building was successfully finished by adding a base-isolation structure, an example of contemporary technology, to the original steel-frame/masonry structure that was an example of one of the most advanced architectural technologies available in Japan at the earliest stage of the Japanese adoption of European-style modern architecture. The Tokyo Station Building (Marunouchi side) saw its grand opening on October 1, 2012, reproducing its 1914 appearance at the initial stage of construction (Photo 5). ■

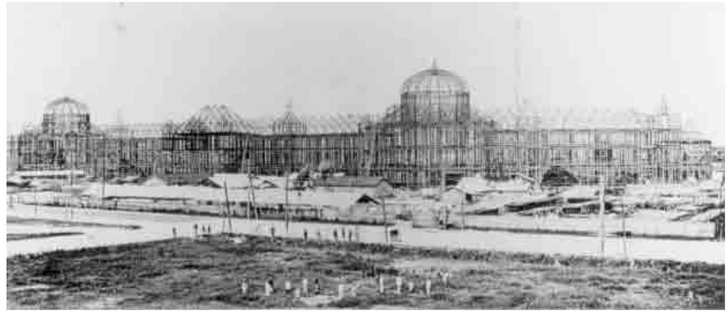


Photo 3 Installation of steel frames[2)]

Photo 4 Advanced base-isolation systems (base-isolation laminated rubber and oil damper) were adopted for securing sufficient seismic resistance of the renewed Tokyo Station Building.

References

1) H. Kanai: Report on Construction of Tokyo Railway Station, Journal of Japan Society of Civil Engineers, Vol. 1, No. 1, 1915
2) Tokyo Station Improvement Office, Japanese Government Railways: Commemoration Photo Album, 1914
3) Photos 1, 2 and 4: Owned by East Japan Railway Company

Photo 5 Image of appearance upon completion (2012)

Development of Prefabricated Steel-frame Housing in Japan

by Shuichi Matsumura
Professor, School of Engineering, The University of Tokyo

Studies of the total floor space of new building construction starts in Japan show that although wooden structures have long accounted for the largest share, in the recent economic bubble period, steel-frame structures have suddenly captured the top spot. I believe that amidst the worldwide construction market, it is only in Japan that steel-frame structures comprise the largest share of total national building construction, outstripping both RC and wooden structures. It can be said that Japan is uniquely a "great country for steel-frame structures."

When considering structures that are representative of steel buildings in Japan, some people call to mind high-rise office buildings such as the Kasumigaseki Building, Japan's first full-scale high-rise building completed in 1967. Still others suggest the ubiquitous, medium-rise buildings that are constructed by attaching ALC panels to framing composed of square steel tube columns and H-shape beams. However, these two types of steel structures alone cannot command the largest share of steel building construction. There is another type of steel-structure building that also accounts for a considerable share of the floor space in new building construction starts. This type consists of low-rise prefabricated steel-frame buildings such as steel-frame detached homes and apartment buildings.

Light-gauge Steel Shapes for Structural Use

The history of prefabricated steel-frame housing in Japan dates back to 1955 when light-gauge steel shapes were domestically produced by means of cold forming. Following the Meiji Era (1968~1912), development of the Japanese steel industry was considered a national priority and was steadily realized with support provided mainly through public demand. However, with the end of the Second World War and the negotiated cease-fire of the Korean War, there was strong sentiment for the steel industry to cultivate new sources of steel demand, i.e. for private demand to replace military demand.

Given this situation, broad attention was directed at the building construction market, which was expected to show rapid growth. In order to effectively establish a new steel market in building construction, it was necessary to develop the technology to produce light-gauge shapes such as channels etc. by cold-forming steel sheets with thicknesses of 2~6 mm.

As soon as the domestic production of light-gauge shapes by means of cold forming became available, the Japanese steel industry quickly started developing applications for these shapes. The Light-gauge Steel-frame Association was inaugurated by the Kozai Club (an association for developing new steel markets, which then merged with the Japan Iron and Steel Federation). The leading figures of the time and promising young researchers in the field of architecture as well as many scholars in a wide range of fields, from structural and planning engineering to architectural design, participated in the Association's work. Their goal was to design guidelines for houses, school buildings and other low-rise buildings employing light-gauge shapes and to develop structuring methods including joining details. Further, trial designs and construction formats were accumulated at a rapid pace.

Prefabricated Houses Employing Light-gauge Steel Shapes

From around 1960 when these efforts started to yield results, the housing market started to show signs of rapid growth, and many companies that had been engaged in non-building operations started moving into this promising market. The companies that advanced from the steel, chemical and home appliance industries focused on the production and supply of highly industrialized (prefabricated) houses, in contrast to wood-framed houses that depended on traditional carpentry skills. Consequently, these companies, or homebuilders, directed their attention to the application potential of the light-gauge shapes that had just come to market. In those days, light-gauge shapes were already being marketed by the giants of the steel industry as ready-to-use structural members for building construction.

While the home structural methods employing light-gauge shapes differed from one prefabricated steel-frame homebuilder to another, the framing method was nearly the same for every builder-channels and square tubes were used as column members while channels and light-gauge H-shapes were used as lateral framing and truss members. Compared to the precast concrete wall method, this method of steel framing gained popularity because of the flexibility in arranging rooms that was permitted by conventional wood framing methods. As a result, prefabricated steel-frame homebuilders directed their marketing efforts not only towards expanding sales volume but also towards steadily expanding

Photo 1 A prefabricated steel-frame house in the initial day and marketed in 1960. Brilliant aluminum wall, new steel sash, and plastic-made eaves and buttress were impressive.

Photo 2 A prefabricated house in the first part of the 1960s, which is remained in a homebuilder's research institute.

floor plan flexibility, which has allowed these homebuilders to gain their current leadership position in the Japanese housing market.

At the infancy of prefabricated steel-frame housing around 1960, some houses demonstrated a "novel feature" that was regarded somewhat strangely by people accustomed to conventional wooden housing. Whereas it had been common for the joints between wall panels to be clearly visible from outside the home, the new approach of covering the exterior walls with aluminum and other materials took people by surprise. (See Photos 1~4) Further, because mass production was almost unheard of at prefabricated homebuilding plants at this time and the kinds of structural members produced were few, only a limited variety of outer wall configurations were available in the structural plans. For example, the catalogs of that time showed only one or two floor plans.

In the latter part of the 1960s, prefabricated home design adopted methods used for wooden houses. The selection of "ready-made plans" from a restricted catalog of designs was replaced by flexible design systems that allowed homebuyer requests to be incorporated in "custom-made" plans. New importance was placed on how to realize the dreams of each homebuyer in the construction of their own homes, rather than on the preparation of future home designs drawn by architects, structural engineers and other professionals. As a result, prefabricated steel-frame housing was accepted in the Japanese housing market, and prefabricated homes were established in society as a new type of housing different from conventional wooden homes.

Photo 3 Midget house, one of prefabricated houses in the initial days, which was marketed as a study room installed in the garden. It is exhibited in a homebuilder's research institute.

Photo 4 One of prefabricated steel-frame homes, developed in 1961

The Prefabricated House as a Mass-produced Product

In 1970, just 10 years after a number of companies entered the prefabricated steel-frame housing market, some emerged that annually sold more than 10,000 houses. In the 1980s, in spite of the severe operating environment caused by the oil shock and other events, the number of homebuilders that annually produced and sold more than 10,000 homes increased further, and systems were developed for building homes with three or more stories employing heavyweight steel frames (Photo 5).

Based on the concept of using enhanced shop-production ratios to achieve a level of cost performance appropriate for prefabricated housing, a succession of new structural methods were developed: one was a method to design large panels, and another was the unit method whereby individual rooms are shop-assembled (Photo 6). As a result, housing supplied by prefabricated homebuilders has taken on the character of being mass-produced and mass-marketed.

♦ ♦ ♦

Lastly, I wish to comment on a task confronting all prefabricated steel-frame homebuilders. In an operating environment of moribund housing starts, the problem of how to effectively use the "closed" structural systems unique to each homebuilder demands our attention. Such systems in the current environment are no longer rational or viable; in fact, there are cases in which they constitute an operating burden for the individual builder.

However, because these companies have accumulated considerable specific knowhow over the last 50 years regarding the details of their respective closed structural systems, it is my conclusion that now is the time for them to consider terminating the use of their closed proprietary systems and to collaborate in bringing to market an open system that will promote sustainable development of the prefabricated steel-frame housing industry as a whole. ■

Photo 5 Example of 3-story house employing heavyweight rigid steel frame system

Photo 6 From around 1970, extensive efforts were directed toward developing the structural method that enhances the prefabrication ratio (photo: an example of unit system housing production line).

Acknowledgment

The author wishes to thank the following companies for their generous cooperation in providing the photos and figures used in this article: Sekisui House, Ltd., Daiwa House Industry Co., Ltd., PanaHome Corp., Asahi Kasei Homes Corp. and Sekisui Chemical Co., Ltd.

Prefabricated Steel-frame Housing in Japan

by Japan Prefabricated Construction Suppliers & Manufacturers Association

Development of Prefabricated Steel-frame House Technologies

Progress of Prefabricated Steel-frame Housing

In Japan, the production of light-gauge steel shapes started in the late 1950s. These shapes drew attention as new steel products for use in building construction.

The Light-gauge Steel-frame Association was established in 1955 under the auspice of the Kozai Club (an association of steelmakers and traders in Japan) with a focus on the research and development on applications for light-gauge steel shapes in the construction of small-scale buildings. While light-gauge steel shapes were first used mainly for purlins, furring strips and other secondary structural members, the Association's extensive R&D efforts steadily expanded their use to include core structural members such as beams, columns and trusses. The design and construction technologies yielded by these R&D efforts served as a starting point in the structural design of prefabricated steel-frame houses.

Because the framing of structures employing light-gauge steel shapes resembles the wood framing methods conventionally used in Japan, many companies initiated their own development of prefabricated steel-frame houses. As a result, prefabricated steel-frame homes account for about 80% of all prefabricated housing starts in Japan, even today.

The exterior and interior members of prefabricated steel-frame houses are manufactured at plants offering high-level quality control systems. As a result, high-quality members are supplied on a stable, constant

Rigid frame system (Asahi Kasei Homes)

Framing brace system (Sanyo Homes)

Box rigid-frame unit system (Sekisui Chemical)

Panel frame system (Sekisui House)

Framing brace system (CEL Corp.)

Framing-panel combined system (Daiwa House)

Framing system (Toyota Home)

Framing system (PanaHome)

Unit system (Misawa Homes)

Photo 1 Representative prefabricated steel-frame homes marketed in Japan basis by manufacturing lines at these plants that in addition to roll forming, cutting, drilling and welding also provide highly corrosion-resistant coatings.

Welding, cutting and drilling operations are no longer needed at home construction sites because shop-manufactured members with high dimensional accuracy are delivered for assembly, which allows building of high-quality homes.

Among the main structural methods for prefabricated steel-frame houses are the panel framing system, framing system, framing-panel combined system, the rigid frame system using heavy-weight steel frames, and the unit system. Homebuilders offering multiple structural systems are promoting the development of houses and housing projects that meet specified building applications and regional needs. (See Photo 1)

These structural systems were originally developed by various prefabricated homebuilders. Even within the same framing system, the structural system differs by homebuilder.

The main structural systems adopted for building prefabricated steel-frame houses by respective prefabricated homebuilders in Japan are introduced below:

Framing System

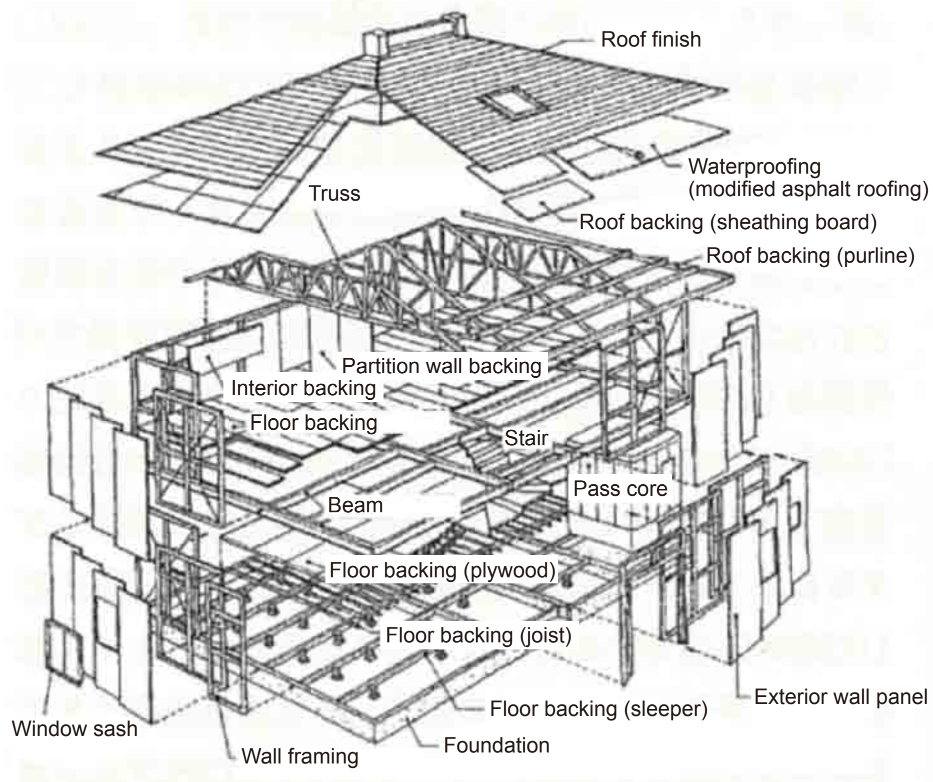
● Panel-Frame System

A typical framing system in this category is the panel-frame system developed in 1960 by Sekisui House, Ltd. The system mainly employs C-shaped light-gauge steel. At a time when houses were most commonly built of wood, the homes built using the system employing steel, aluminum and plastics as the main structural materials were highly innovative.

In 1961, the company improved on its initial homes with the development of new structures with high performance and a new structural design (Photo 2). Many epoch-making improvements, that were well ahead of competing homebuilders, were incorporated into the new design. Specifically, the metric module (1,000 mm) was adopted, and, in order to increase vertical expanse, the ceiling height was increased to 2,400 mm, 300 mm higher than the minimum standard height prescribed in the Building Standard Law. Sandwich panels composed of styrene foam and aluminum were adopted for the exterior walls to improve thermal insulation. While a simple gable roof was adopted, the girders were lengthened to extend the eaves by about 1 m; this was to provide devices to prevent the influx of rainwater during the rainy season and to block off sunlight during the summer.

Photo 2 Panel frame system originally marketed

Fig. 1 Outline of Panel-frame System



The windows incorporated newly marketed aluminum sashes to improve installation precision. The interiors were finished by replacing the plastic members used widely in the initial-stage homes with wooden members, which led to more appealing to the tastes of the Japanese people. (Fig. 1)

In 1962, two-story houses adopting the new system in an overlapped form were developed, and in 1964, split-level 2-story houses with improved design performance were developed that employs an original steel framing system (Photo 3). The new system allowed for effective structural designs that met not only the need of homebuyers for flexibility in locating the 2nd story and arranging rooms but also to meet legal specifications. (Photo 4)

In the newly-developed system, the bearing walls contain steel braces (pivotal to securing seismic resistance) assembled in an X-shape and are arranged independently on the 1st and 2nd floors in order to secure compatibility between design freedom and structural strength.

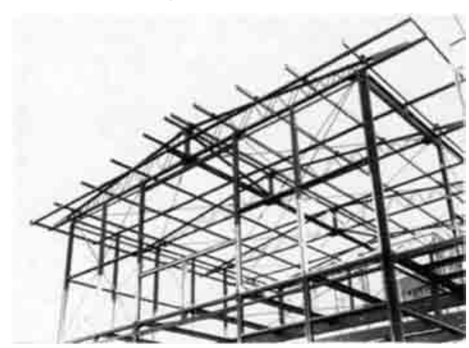


Photo 3 Original panel-frame system

Photo 4 Shop production line of panel-frame system

In 2003, a base-isolated house was developed that has attracted attention for offering the highest level of seismic resistance. Further, research efforts were promoted to develop response-control technology with excellent cost performance, and in 2007 its own seismic motion energy-absorbing system was introduced in housing design. This system absorbs seismic vibrations by replacing some of the bearing walls used as seismic-resistant structures with seismic motion energy-absorbing frames containing special dampers (Photos 5 and 6). Development of this new seismic energy-absorbing system allows the panel-frame housing system to offer a full lineup of quakeproof performances: seismic resistance, response control and base isolation.

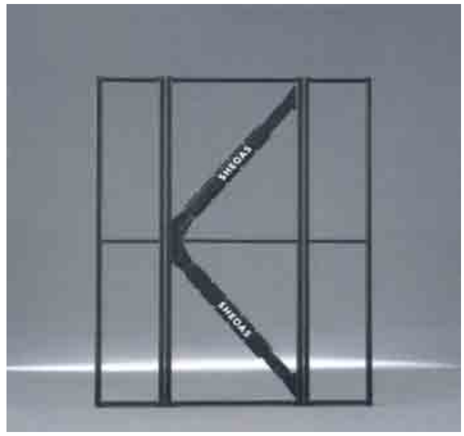


Photo 5 Framing system into which damper is assembled

Photo 6 Seismic energy-absorbing system

● Framing-Panel Combined System

Another typical system in this category is the framing-panel combined system developed by Daiwa House Industry Co., Ltd. Prefabricated steel-frame housing that employs this combined system reduces on-site execution processes and the construction term by completing the wall panels (exterior member, thermal insulation material and interior substrate) and attaching them to the steel frame at the shop and then assembling them at the construction site. This basic concept has shown no change since the system was developed. (Figs. 2~4)

Because of the need to join each of the panels with a closed structure by use of an exterior member and an interior substrate, channel-shaped connectors (columns) are required between the panels. And, when joining the panels to a reinforced-concrete foundation and an upper girder, it is necessary to embed nuts in the panels and to prepare the joining material in advance. The housing frame can be structured with typical, module-allotted panels even in the plans with external and internal angles, by conforming the width of connectors with the thickness of panel frames as well as by situating a datum line at the center of external wall panels.

This approach constitutes the basis of the panel-framing combined system. The size of the module was set at 940 mm, which is close to 945 mm, half the size of Japan's traditional *tatami* mat. Further, the 940-mm module size was derived from the view that the 1,820 mm size, twice that of the exterior walls then available, be usable without any loss. (When the 60 mm gap between connectors is added to 1,820 mm, the total size becomes 1,880 mm, and half of 1,880 mm is 940 mm.)

Fig. 2 Framing-Panel Combined Method

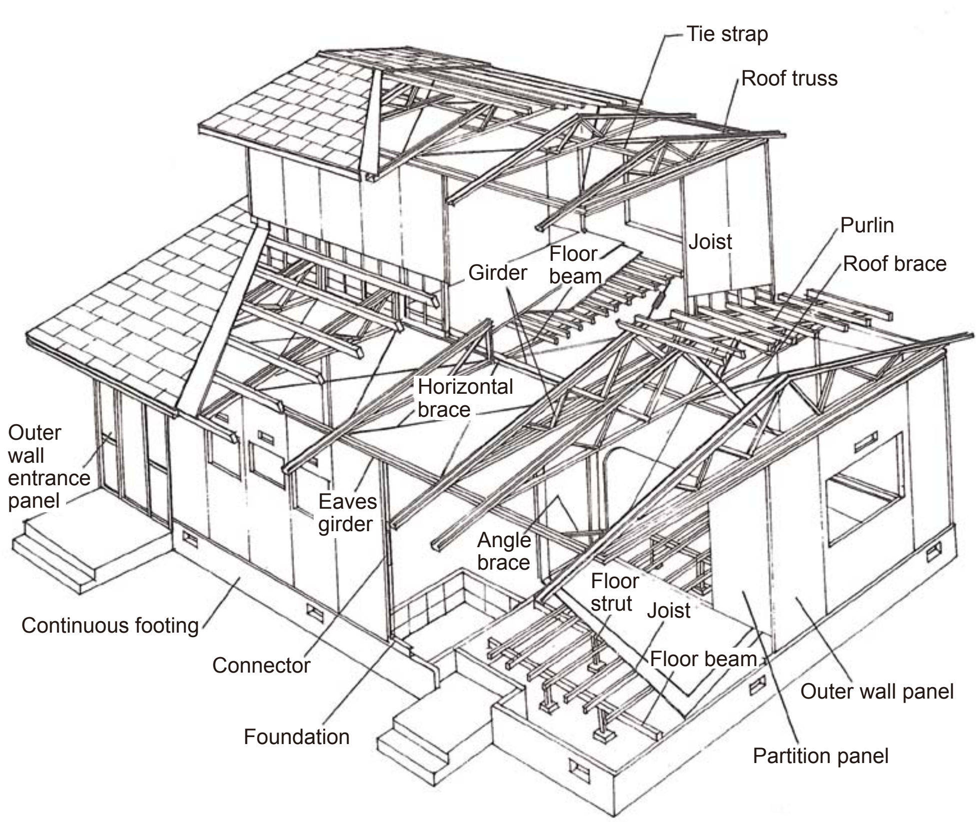
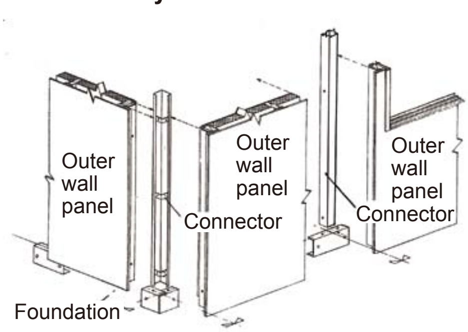


Fig. 3 Panel Assembly of Framing-panel Combined System



However, in order to improve the dimensional efficiency of the interior structural members of the floor and ceiling panels, not the dimensional efficiency of the exterior wall structural members, the 940 mm module size was modified to about 910 mm, which is the average size of currently available structural members. Further, the datum line, which originally was located at the center of the structural core, was put on the

Fig. 4 Plan of Framing-panel Combined System

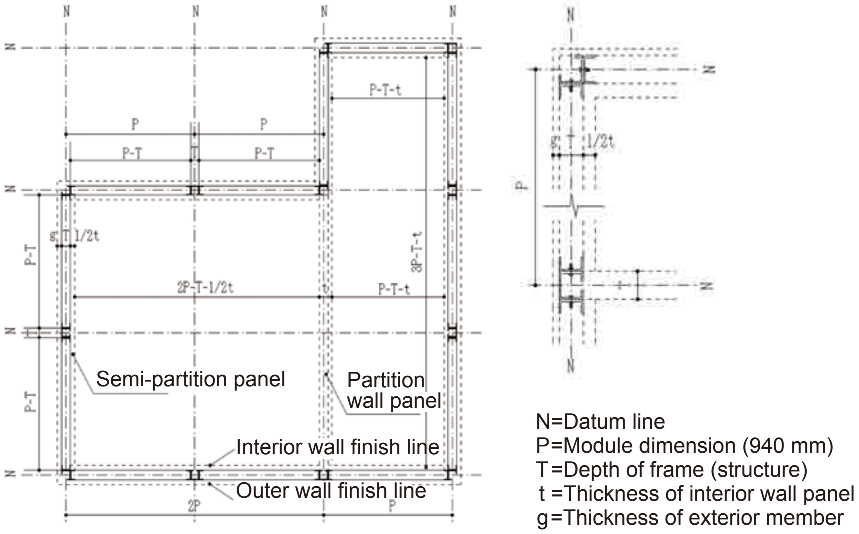
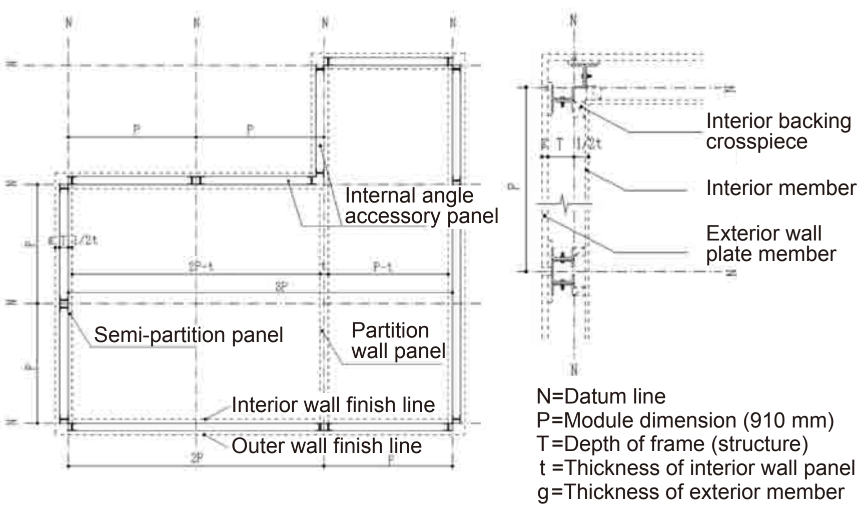


Fig. 5 Plan of Framing-panel Combined System (Improved System)

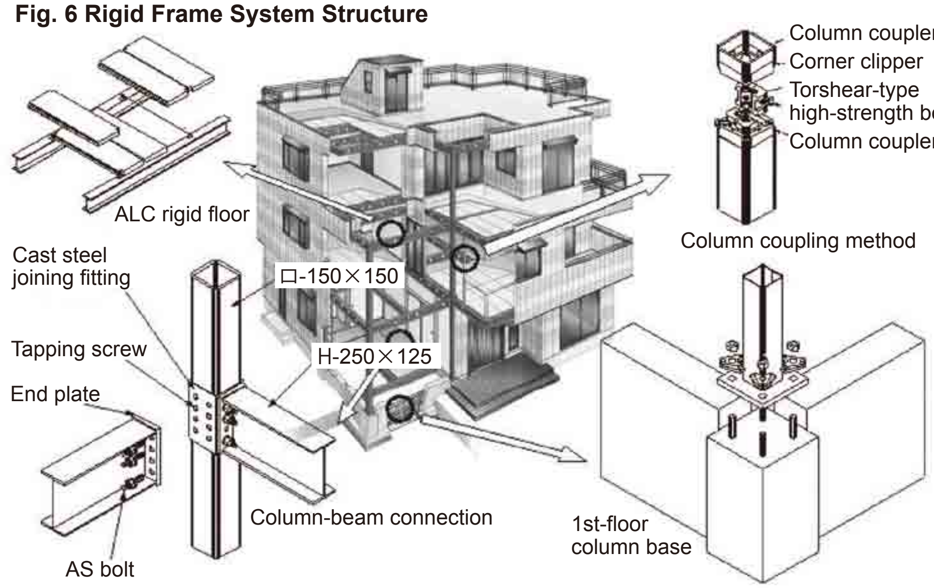


inner side of the structural members to reduce the use of unique panels especially for ceiling edges etc. As a result, the plan and the plan detail were changed to those shown in Fig. 5 (improved type).

The initial plans for 2-story prefabricated housing with many room numbers has been improved to allow for large spaces and openings and to provide a partial stiffening system for the structural members (lateral framing and high-strength bearing panels).

In 3-story housing construction, while the panel-framing combined system has certain difficulties in meeting every homebuyer's request, the system does have the advantage of allowing housing construction on narrow sites in urban areas.

Fig. 6 Rigid Frame System Structure



Rigid Frame System

● Rigid Frame System Structure

Characteristic of rigid frame systems are the rigid frame structures of Asahi Kasei Homes Corporation. In this system, H-shape beams are touch-joined directly to square steel tube columns in an end-brace form, and rigid joining is realized by the use of special high-strength bolts. It is this housing system that allowed the prefabrication of rigid-frame structures capitalizing on mass-produced parts and simple framing, while the prefabrication of rigid-frame housing structure continued to be difficult when using conventional methods.

In 1985, the new rigid-frame housing system was completed by means of the original method using beam-column joints and column bases. For the latter, the exposed-type column base method was adopted by which the column bases are fixed by pouring grout mortar from a special washer; for column-to-column joining, weld-free bolt joining (column coupler method) was adopted. This system features an on-site weld-free housing system. (Fig. 6)

Compared to brace structures, the rigid frame system offers greater freedom in plan design, and in 1986, a 3-story house employing this system was marketed, which led to a rapid expansion of the 3-story housing market (Photo 7). Further, because fireproofing can easily be secured for 3-story rigid frame structures compared to brace structures, the rigid-frame 3-story housing system gained market acceptance as a method of medium-rise apartment house framing, thereby leading to the expansion of the medium-rise apartment housing market.

The range of applicable member sizes was expanded in order to develop a rigid frame system employing 250-mm square steel tube columns. Three to five story structures that employ this system are not used solely for apartment housing but also for composite structures zoned for combined shop and apartment use.

Currently, the rigid-framing system uses 150-mm steel tube columns and supplies diverse kinds of houses to the 3~4-story housing market, thereby meeting today's extensive need from medium-rise urban housing (Photos 8~10).

Photo 7 3-story house employing rigid frame system

Photo 8 Urban-type 3-story house employing rigid frame system

Photo 9 Exhibition model house employing rigid frame system

Photo 10 4-story house of composite use type employing rigid frame system

Unit System

● Steel Unit System

Among unit systems is the steel unit system developed by Sekisui Chemical Co., Ltd. In this system, a housing structure is divided into multiple structural units, which are shop-manufactured to a nearly finished state. These units are then transported to the construction site and assembled to complete the house. At a time when great numbers of houses were needed, the steel unit system with its high shop productivity was able to produce high-performance and high-quality housing.

The first steel unit system house was marketed in 1971. This system featured a high degree of shop prefabrication of unit box rigid frame structures. Assembly of each unit structure was easy, which made it possible to meet the need for detached houses with complex plans and specifications. (Photos 11~13)

Photo 11 House employing unit system

Photo 12 Installation of unit structure

Photo 13 Production line for unit system housing

The first houses of this type adopted a standard dimension of 800 mm (currently 900 mm)–a simple system in which structural units measuring 2,400 mm in width, 5,600 mm in length (external dimension: 5,000 mm) and 2,700 mm in height were regularly arranged in terms of both plan and elevation. The difference in loading conditions at the 1st and 2nd stories was met by changing the section size and wall thickness of the adopted column and beam members. A notable feature of these homes were gabled exterior wall sections that projected from the unit's gabled side, which facilitated the smooth joining of each unit and their use as storage spaces. (Figs. 7 and 8)

In order to meet ever more divergent demands for plan, price and design, the kind of units available has multiplied and the assembly method for these units has evolved. The following three types are cited as particularly characteristic:

Fig. 7 Unit System Structure

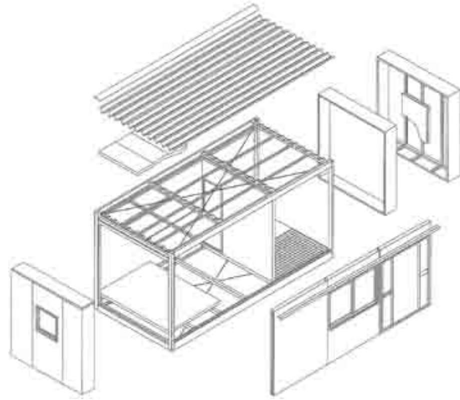
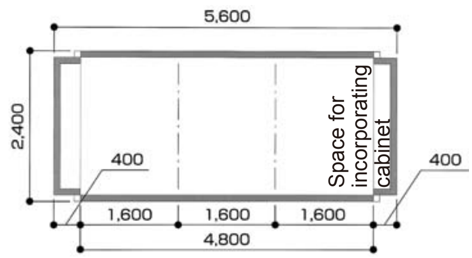


Fig. 8 Module of Initial-stage Unit System



- Sub-units: These units have half the width of a standard unit. This greatly improves freedom of design with regard to floor area and building site.
- Roofing method: This method is used to build triangle-shaped roofs. Diverse roof shapes can be completed in one day by dividing the roof structural members into roof units and panels.
- High beam method: This method allows the central column section, consisting of four 1st-story units, to be removed by on-site reinforcement of the 2nd-story floor beam section. This approach allows for the provision of large spaces (equal to a maximum of 33 *tatami* mats) that are free of walls and columns, a feature that is unavailable in conventional housing (Photo 14).

Photo 14 High beam method

● Unit System

Another unit-type housing system is the one developed by Misawa Homes Co., Ltd. The development of the system started with the company's entry in the "House 55 Proposal Competition" sponsored by the then Ministry of Construction and Ministry of International Trade and Industry in 1976. The Misawa's housing system is a rigid steel-frame structure with "multifunctional" new bearing walls (ALC walls) featuring excellent performance in structural strength, fire resistance, and thermal and sound insulation (Photo 15, Fig. 9).

Fig. 9 Production Process for Outer Walls Employing Multi-function ALC Panels

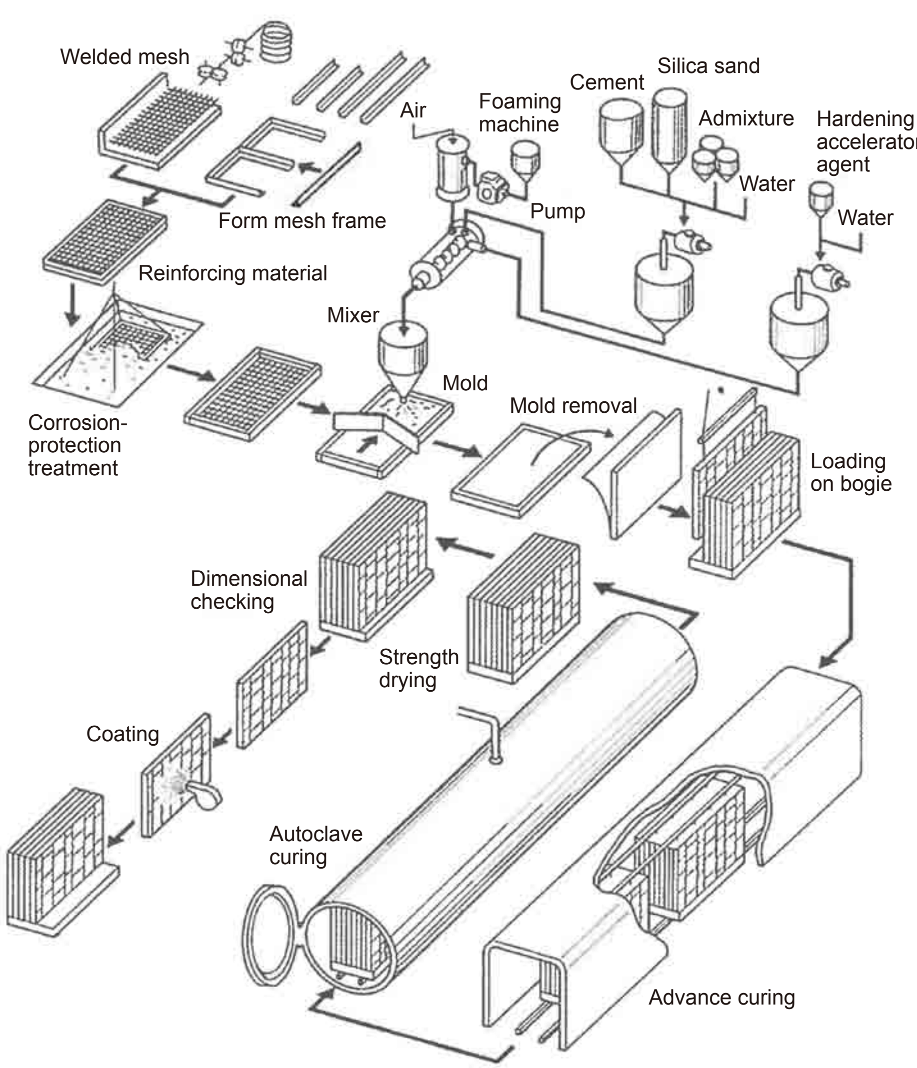


Photo 15 House employing steel rigid frame unit system (combination bearing wall/rigid steel-frame housing structure)

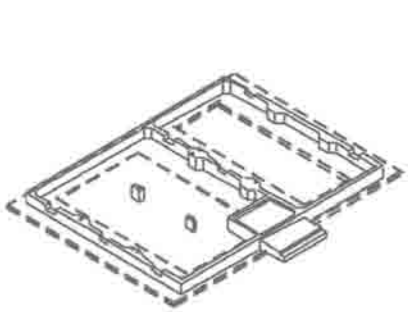
In 1989, Misawa Homes enhanced the unit-type housing system to develop a capsule (box) unit rigid steel-frame system, in which each capsule unit is finished as a complete single-shell box structure. Each capsule unit adopts 125-mm square steel tubes for the columns and 175 mm light-gauge steel channels for the beams: these members are weld-joined to form a single rigid frame box structure per span and layer; and these box structures are then joined vertically and horizontally, using bolts and anchor bolts to complete the whole housing structure (Fig. 10).

Each capsule frame bears vertical load and horizontal forces from earthquakes and winds, allowing easier housing planning in which bearing elements can be arranged in a balanced way and dispensing bearing walls to allow much more freedom to provide large floor-to-ceiling openings.

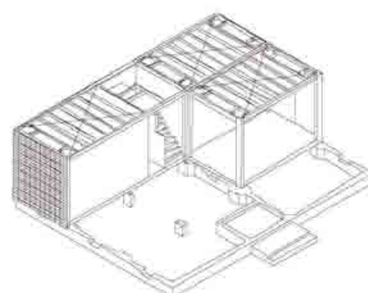
The main objectives in the development of the capsule method were to further enhance industrialization of housing and to increase the speed of house construction. The new capsule unit system has allowed advance at-factory installation of not only exterior walls and exterior members but also interior partition walls and fittings, thereby dramatically enhancing the "industrialization" rate. A higher level of industrialization has also allowed for quality stabilization and less on-site construction work for shorter construction periods (Photo 16).

At the housing construction site, the development of new joining methods and other erection systems now allows for the joining of upper and lower capsule units, as well as neighboring capsule units, using only one high-strength bolt per column. As a result, a process has been established by which everything from erection to waterproofing of the joined capsule units can be completed in one day (Photo 17).

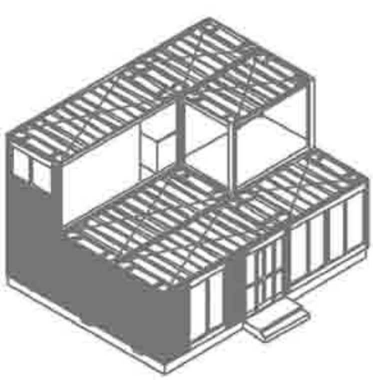
Fig. 10 Assembly Outline in Unit System



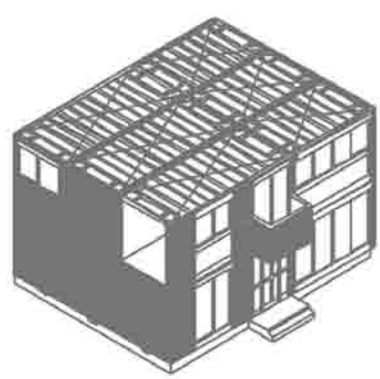
①Completion of foundation placement



②1st-story unit installation



③2nd-story unit installation



④Completion of unit installation

⑤Installation of roof frame and panel

⑥Completion of house

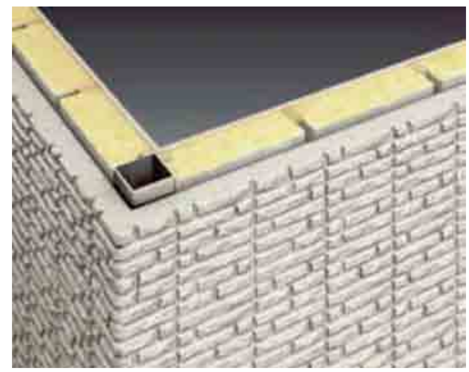


Photo 16 Structural image of double-layer wall in unit system

Photo 17 Installation of unit structure

The Future Direction of Prefabricated Steel-frame Housing

Prefabricated steel-frame homebuilders, in order to realize a low-carbon society, are promoting technological development that will further improve energy-saving performance and expand the use of energy-creation and energy-storage systems.

In addition, homebuilders are directing their efforts toward the development of a stock-utilization society. Specifically, they are promoting technological development for more effective utilization and regeneration of the prefabricated steel-frame houses already supplied and they are pushing for the positive application of legal systems to enlarge and remodel these houses.

Overseas Operations of Japanese Prefabricated Homebuilders

In recent years, Japanese prefabricated steel-frame homebuilders have actively promoted overseas operations. They are extending house-building and town-building projects in the world market, fully capitalizing on the high quality and performance features acquired through the development of prefabricated steel-frame houses in Japan. Typical overseas operations being promoted in China (Sekisui House), Thailand (Sekisui Chemical), and China and Taiwan (Misawa Homes) are introduced below:

Construction of a Housing Plant in China

Sekisui House promotes housing projects in Australia, Singapore, the United States and China.

In April 2012, the company completed in China the construction of a prefabricated steel-frame housing plant and started its operations (Photos 18, 19). This was the first entry of a full-scale prefabricated steel-frame homebuilding plant owned by a Japanese firm into the Chinese market. The plant was built to meet the need for next-generation, energy-efficient, high-performance houses in China. It produces structural members, exterior walls and interior equipment used for detached prefabricated steel-frame houses built in China by the company (Photo 20). The annual production capacity is 72,000 m^2.

Capitalizing on knowhow acquired from the construction of two million houses in Japan and as the top-ranking producer of eco-friendly homes, the company intends to rely on the newly completed production plant as its base of operations in supplying high-quality houses employing a prefabricated steel-frame system to the major cities of China.

Photo 18 Steel-frame home production plant in China

Photo 19 Steel-frame home production line in China

Photo 20 Detached house constructed in China

Production and Marketing in Thailand

Eyeing a completion date in December 2012, Sekisui Chemical is constructing a plant in Thailand for the mass production of detached houses (Photo 21). The company intends to start full-scale housing operations there in 2013.

A major feature of the company's overseas operations is the implementation of its approach to the housing business as established in Japan jointly with joint ventures with local companies: namely, local procurement and production, and carrying out of a wide range of operations from plant construction to marketing, housing construction and after-sales service.

In order to promote housing operations in Thailand, two joint-venture companies (marketing and production) were established jointly with Thailand's largest conglomerate. The two-year verification of the production system, marketing method and cost performance was carried out by these two ventures.

The production plant was constructed in Saraburi Industrial Park (Photo 22, Fig. 11), about 80 km north of Bangkok. Plans call for annual production and sales of 1,000 houses in 2014.

Photo 21 Example of houses constructed in the plots of land for sale by developer

Photo 22 Housing production plant in Thailand

Fig. 11 Location of Thai Production Plant

Successful Operations in China and Taiwan

Misawa Homes has promoted overseas housing operations for nearly 30 years.

In 1986, the company built 134 single-family homes in Beijing and in the following year 14 homes in Tianjin. The company has also built homes in Taiwan, including a model home in Taipei (Photo 23). Visitors to the site exceeded 300 during the first month after opening, an indication of high user interest.

Photo 23 House for sale in lots exhibited in Taiwan

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On the strength of advanced knowhow accumulated in the design and construction of prefabricated steel-frame houses, Japanese homebuilders are expected to further accelerate their overseas operations. ■

Acknowledgment

We wish to thank the following companies for their generous cooperation in providing the photos and figures used in this article:

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- Misawa Homes Co., Ltd.

Steel-framed House Employing Light-gauge Steel Shape

by The Japan Iron and Steel Federation and Steel-Framed House Association

What Is a Steel-framed House?

Steel-framed houses are built with a new construction method that utilizes a non-welding system to connect cold-formed steel shapes made of galvanized steel sheets with a thickness of about 1.0 mm (Photo 1). This new house framing technique is based on the traditional 2×4 stud wall framing method used in the United States. In steel-framed house construction, the lumber frames are replaced by steel frames.

Once the wall and floor panels are prepared, they are assembled in a box-shaped structure or a house. Both sides of the light-gauge steel shapes used for the walls, floors and roof are covered with plywood, gypsum board and other materials. The diverse performance characteristics–structural stability, fire resistance, durability, thermal insulation and sound insulation-required of houses are realized by means of entire composite-section frame structures. From the perspective of "product making," these houses are high–performance units that can be introduced with lower initial investment due to the following reasons.

- Thin plate thickness of the light-gauge steel shapes permits screw joining–eliminating the need for welding.
- The use of galvanized steel sheets removes the need to protect cut-end surfaces and connections against corrosion due to the sacrificial corrosion protection provided by the zinc–eliminating the need for corrosion protection painting.
- The use of design and production systems by means of IT allows every steel shape to be accurately cut per the requirements of each house and shipped from the fabrication plant–eliminating the need for on-site fabrication.
- The major steelmakers in Japan have acquired the necessary approval for steel-framed house construction, which they then provide to the builders–simplifying design.
(Table 1)

Photo 1 Light-gauge steel shapes

Development and Diffusion by Steel Industry Organizations

In November 1994, steel-framed housing was selected as a research topic by the Urban Steel Research Group, the Ministry of International Trade and Industry (currently the Ministry of Economy, Trade and Industry). Developmental work on steel-framed houses in Japan began with the participation of six major steelmakers (Nippon Steel, NKK, Kawasaki Steel, Sumitomo Metals, Kobe Steel and Nisshin Steel) and the Kozai Club (currently the Japan Iron and Steel Federation) who acted as project coordinator. In January 1996, the six major steelmakers established the Committee on Steel-framed Houses within the Kozai Club and commenced joint research on wider topics such as structural performance, fireproofing property and fire resistance, durability, thermal insulation and sound insulation to prepare for full-scale development of steel-framed houses in Japan. Their research successfully resulted in the development of “KC (Kozai Club)-Type Steel-framed Houses. (Fig. 1, Photo 2)

Subsequently, in order to assure a uniform level of quality and to promote the wider use of KC-Type Steel-framed Houses, three major steelmakers—Nippon Steel, JFE Steel (corporate merger of NKK and Kawasaki Steel in April 2003) and Kobe Steel—established the Steel-Framed House Association, whose general membership consists of builders, structural design offices and manufactures. The association conducts the following activities:

- Training courses for structural designers and construction supervisors (completion of training course is an essential requirement for association membership);
- Promotional activities that include the distribution of sales promotion tools, such as pamphlets, publication of house magazines and hosting of website;
- Delivery of formal documents required for construction confirmation applications, loan applications to the Housing Loan Corporation and housing performance assessments; and
- Operation of approval systems for plants to manufacture the light-gauge steel shapes, metal fasteners, screws and nails used in steel-framed house construction

Although light-gauge steel shapes, metal fasteners and screws are pivotal structural members for securing the quality of steel-framed houses, they have yet to be specified in JIS (Japanese Industrial Standards). To compensate for this, the Japan Iron and Steel Federation Standards have been established as a substitute for JIS with regard to these structural members. By doing so, both a standardized level of quality for steel-framed

Table 1 Comparison between Conventional Steel-frame Structure and Steel-framed House

	Conventional steel-frame structure	Steel-framed house
Structural materials	Steel	Steel; Sheathing board
Thickness of steel	Thickness≥ 2.3 mm	Thickness≤ 1.6 mm
Joining	Mainly welding	Mainly screwing (no need for welding)
Corrosion protection	Coating (after welding)	Galvanized sheet (no need for coating)
Steel member fabrication	Fabricator or user plant	Steel shape plant (no need for fabrication)

Fig. 1 Structures of Steel-framed House

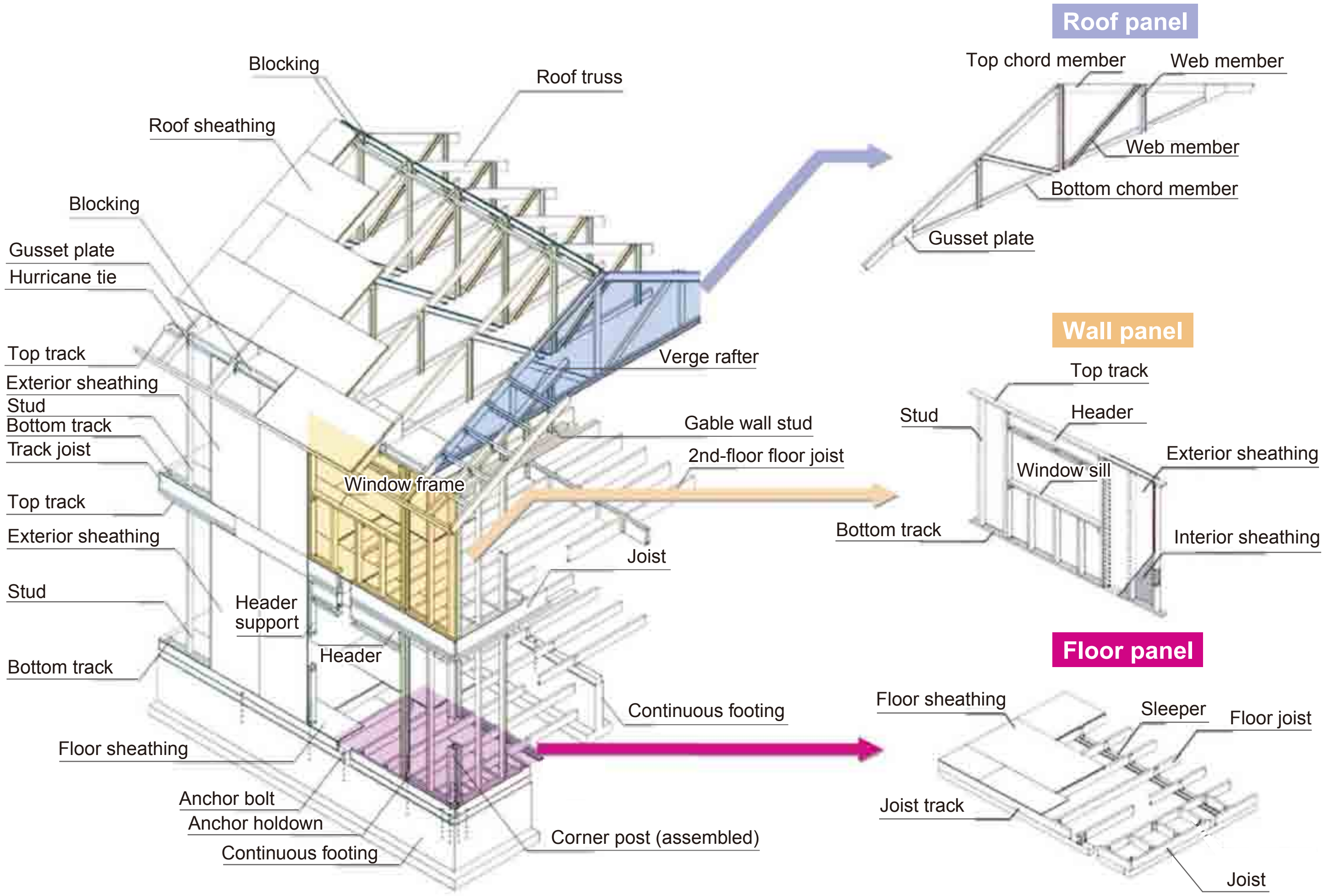


Photo 2 Framing of steel-framed house employing light-gauge steel shapes

houses and a system for approving the plants that will manufacture the parts have been secured.

Growing Construction of Steel-framed Housing

After enforcement by the Ministry of Construction in November 2001 of Technical Standard Notification No. 1641 Concerning Light-gauge Steel Shape Structures, the above-mentioned steel-framed housing method was formally prescribed as a general housing method in the Building Standard Law of Japan. The number of steel-framed housing starts has shown steady growth due to this public notification and to its increasing adoption by major homebuilders as well. ■

Basic Details about Welding and Welding Control

—Welding of Steel-frame Structures—

by Tadao Nakagomi
Professor, Department of Architecture
Shinshu University

For Japan with its frequent great earthquakes, seismic design is very important. In a great earthquake, while it is assumed that collapse will occur in wooden and concrete structures, it is commonly understood that seismic design has provided steel structures with sufficient seismic resistance. However, there are cases in which inappropriately applied welds can become the starting points of fractures that lead to steel structure collapse.

The following presents the basic details about welding and welding control in steel-frame building structures and regarding key dynamic performance characteristics of welds.

Non-scallop Method

In the welding of steel-frame structures, two methods—scallop and non-scallop—are used. In Japan, the scallop method is more extensively adopted. Fig. 1 shows an example of the non-scallop method, and Fig. 2 an example of the scallop method. In welding operations using the scallop method, because grooves can be prepared inward, welding can be conducted at both the fabrication plant and the construction site. On the other hand, with the non-scallop method, because grooves are prepared outward, welding can be applied only in a flat position and, accordingly, cannot be applied at the construction site.

Fig. 1 Non-scallop Method

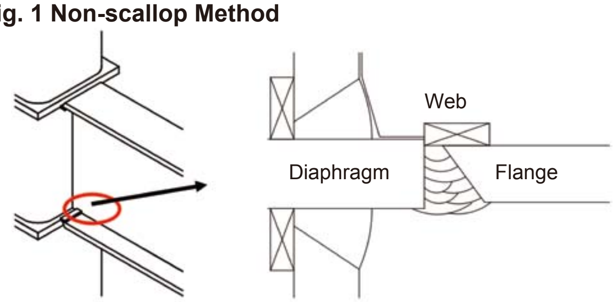


Fig. 2 Scallop Method

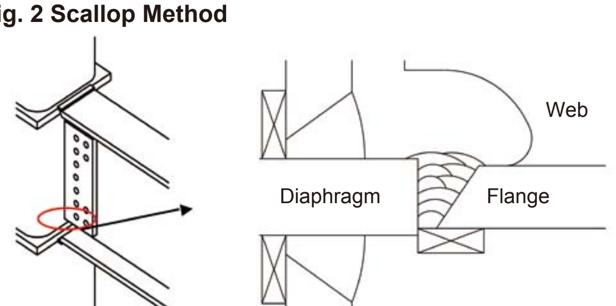
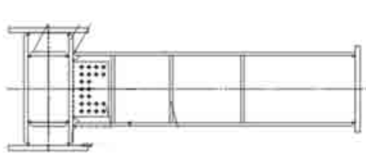


Fig. 3 Configuration of Test Specimen for Beam-to-Column Joint



In order to compare the differences in yield strength between scallop and non-scallop methods, a test was made using the beam-to-column joint specimen shown in Fig. 3. The test was conducted by setting the loading amplitude as the steady increment positive-negative alternating loading. The test results for load-displacement relations are shown in Figs. 4 and 5[2),3)]. As shown in the figures, the yield strength of on-site scallop welding shows extremely low values compared to those of non-scallop welding done in the shop. Accordingly, the non-scallop method is adopted because sufficient deformation capacity is provided for shop-welded beam-to-column joints.

On the other hand, in order to provide sufficient yield strength even for beam-to-column joints that are welded on-site, it is necessary to use the drilled flange method (Fig. 7) to improve the deformation capacity of beam-to-column joints by using a haunch to expand the beam width (Fig. 6). Figs. 8 and 9 show the difference in deformation capacity of beam-to-column joints when the drilled flange method is applied and when it is not[2)].

Fig. 4 Test Results for Relation between Load and Displacement in On-site Scallop Method

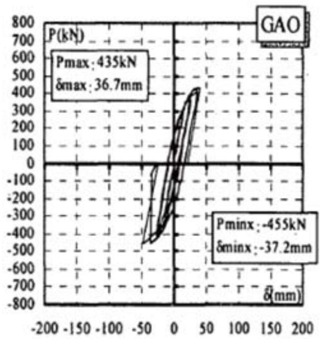


Fig. 5 Test Results for Relation between Load and Displacement in Shop Non-scallop Method

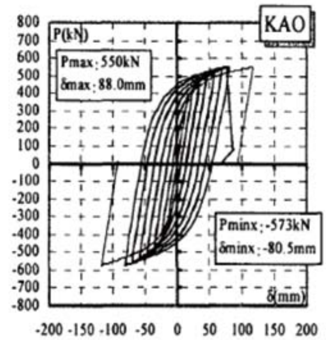


Fig. 6 Example of Horizontal Haunch Method

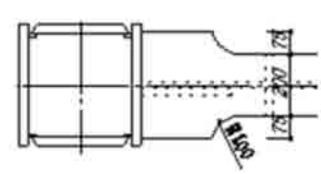


Fig. 7 Example of Drilled Flange Method

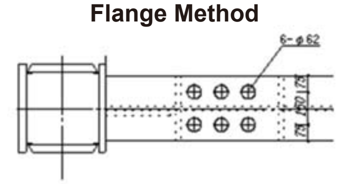


Fig. 8 Deformation Capacity of Beam-to-Column Joint by No Use of Haunch and Drilled Flange Method

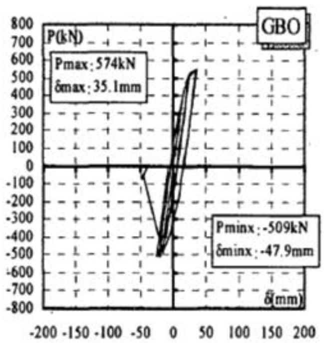
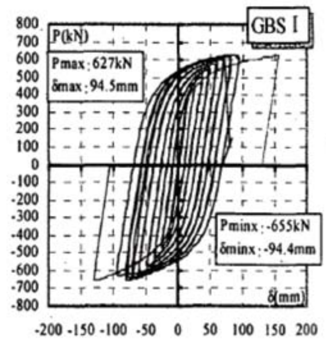


Fig. 9 Deformation Capacity of Beam-to-Column Joint by Use of Drilled Flange Method



Welding Conditions

The mechanical properties of the weld metal, whether good or bad, are strongly related to the welding conditions. In particular, it is known that heat input and interpass temperature have a considerable effect on the tensile strength, yield point and toughness of the weld metal. The heat input is calculated using Equation 1.

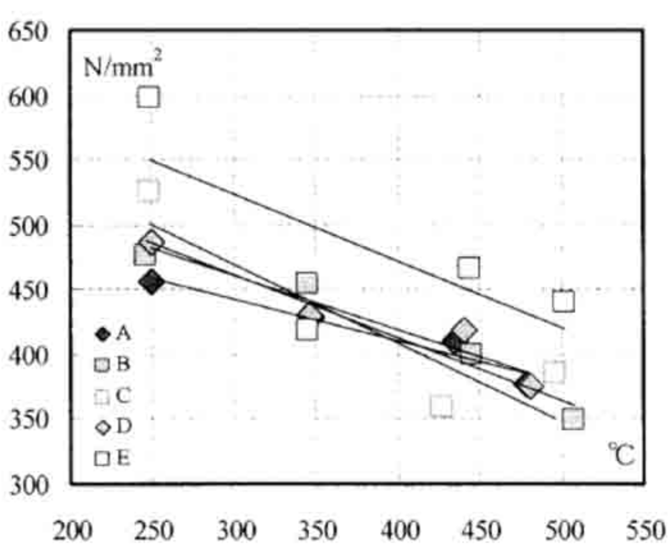
$$H = \frac{60 \times E \times I}{V} \quad \cdots \text{(Equation 1)}^{1)}$$

Where

H : Welding heat input (J/cm)
I : Welding current (A)
E : Arc voltage (V)
V : Welding speed (cm/min)

As shown in Fig. 10, as the heat input and interpass temperature increase, the yield strength drops regardless of the kind of welding wire adopted. The appropriate heat input and interpass temperature differ depending on the type of steel product used. To illustrate, in order to secure dynamic properties for welds of steel products equivalent to SM490, the appropriate heat input and interpass temperature are: an interpass temperature maintained at 350°C or lower, a heat input of 40 kJ/cm or less, and a wire extension of 20~30 mm. In cases where the wire extension is excessive, the welding current and voltage become unstable, thereby causing inadequate shield effect and deterioration in toughness.

Fig. 10 Relation between Interpass Temperature and Yield Point



End Tabs and Backing Metal

● Kind and Performance of End Tabs

Steel end tabs are auxiliary devices attached to both ends of a groove and are used to eliminate non-uniform welding from occurring at either the starting point or the finish point in groove welding. It is feared that stress builds up in the slit section formed between the steel end tabs and the base metal, thereby forming starting points for fracturing. However, when the welding conditions mentioned earlier are satisfied, sufficient deformation will occur in beam-to-column joints to cause fracture.

Solid end tabs are ceramic and are easily attached to the base metal by pressing them against the metal with galvanized wire, rather than by welding. Because solid end tabs are removed after welding, stress concentration caused by the slits does not occur. However, depending on the skill of the welding operators, weld defects are still liable to remain at the start and finish points in groove welding.

In order to compare the effect of weld defects on weld joint deformation, a test similar to that used in the "Non-scallop Method" described above was conducted using a test specimen employing an H-400×200×13×21 beam member. Fig. 12 shows the deformation test results for a beam end with a weld defect located 40 mm in the beam-flange width direction and 10 mm in the thickness direction (Fig. 11); Fig. 13 shows the results when no weld defect is present[4)5)]. As shown in the figures, the deformation capacity of a weld joint drops remarkably when a weld defect is present. Accordingly, it is necessary to use ultrasonic flaw detection tests to confirm that weld defects do not occur.

Fig. 11 Position of Providing Welding Defect

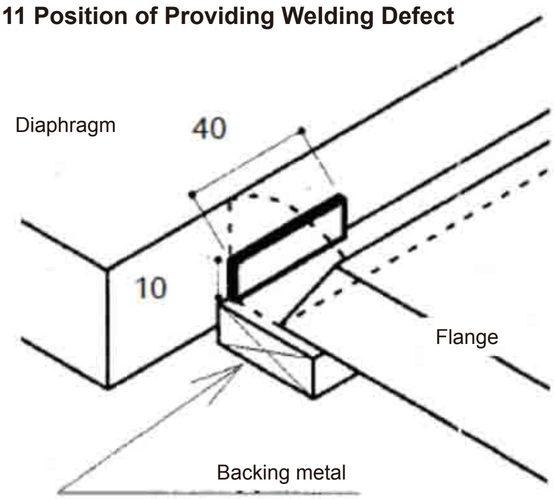


Fig. 12 Test Results for Deformation Capacity of Beam-to-Column Joint in Provision of Weld Defect

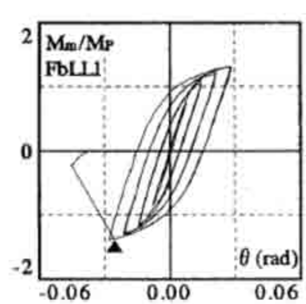


Fig. 13 Test Results for Deformation Capacity of Beam-to-Column Joint in No Provision of Weld Defect

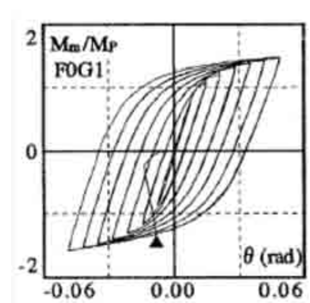
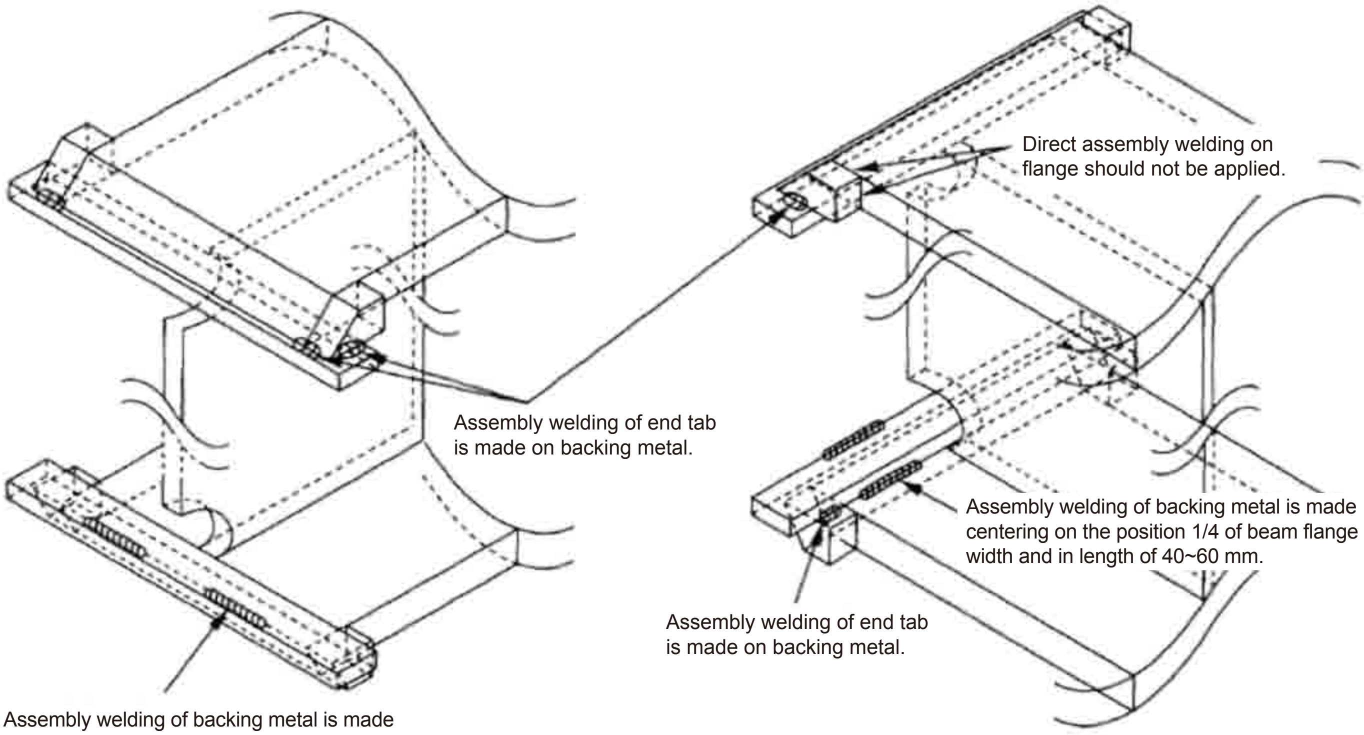


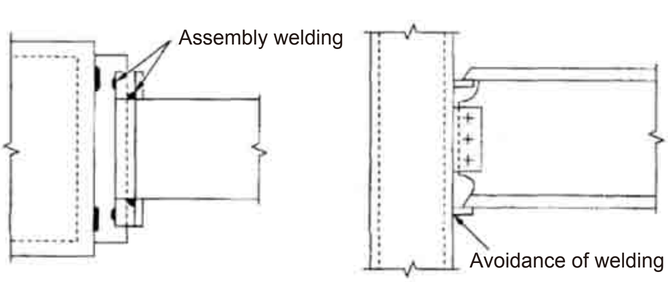
Fig. 14 Shop Assembly of Backing Metal and End Tab[2)]



● Tack Welding of the Backing Metal and End Tabs

In beam-to-column welding, backing metal is used to prevent the weld metal from falling off. In assembly welding that uses backing metal, welding that is 4~6 mm wide and about 40~60 mm long are made on both the column and beam flange sides and are placed at four locations centered on positions 1/4 of the beam flange width. When attaching the backing metal and end tabs, the end tabs are tightly attached to both the beam flange and the backing metal, but welding is conducted only on the backing metal and should not be applied to sections where the end tabs and beam flanges are in mutual contact (Fig. 14). In the case of on-site welding, it is feared that when welding is conducted in the periphery of scallops or when lower-flange backing metal is welded from its lower side (Fig. 15), brittle fracturing will result, and thus, such welding should not be applied[1)6)]. ■

Fig. 15 On-site Assembly Welding of Lower Beam Flange



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Steel Construction in Thailand

–Current Situation and Future Directions–

by S. Leelataviwat, Assistant Professor, Department of Civil Engineering, King Mongkut's University of Technology Thonburi; Member of the Committee on Steel Structures, Engineering Institute of Thailand

Construction is one of the most important steel-consumption industries in Thailand, accounting for up to 60% of the nation's total steel consumption. Despite key advantages of steel structures, the construction in Thailand is mainly dominated by concrete. The use of steel has been primarily limited to bridges and to industrial and landmark buildings. Compared to other countries in the same region, per capita consumption of crude steel for Thailand is remarkably low (Fig. 1). Hence, there still exists a significant growth potential for Thailand in terms of steel usage.

Records of steel structures in Thailand dated back to the later part of 1800s. The influx of western technology and expansion of Bangkok brought along the first applications of steel structures. The early use was limited mainly to small bridges and railway stations. By the 1910s, most of the early steel bridges had been replaced by concrete bridges. The main reasons for replacing steel structures with concrete structures were lack of maintenance and the general belief that concrete structures would be more durable in humid environment typically experienced in Thailand. With the first introduction of relatively-cheap and locally-produced Portland cement in 1910s, the use of concrete structures increased significantly. It was widely believed that labor being cheaper in Thailand meant that efficient design ideas would be primarily governed by material savings. This led finally to the widespread application of concrete structures in Thailand.

Presently, other factors that also contribute to the reluctance in using steel structures include the followings.

Limited material supplies: Because lack of domestic upstream steel production facilities and a relatively small market, the type of steel available in Thailand is mainly limited to a certain grade (Fy = 245 MPa). With limited material options, the difference in the construction costs between steel and concrete structures remains sizable.

Stringent fire resistance requirements: Thailand has a very stringent fire code requiring unnecessarily high fire rating, in most cases. The costs of fireproofing can amount to a significant portion of the entire structural costs in some projects.

Lack of knowledgeable and qualified professionals: The majority of the architects, engineers, and contractors have been trained and worked primarily with concrete structures. At the moment, there is a shortage of qualified professionals involved in the design and construction of steel structures.

Advancing the Use of Steel Structures in Thailand

The low steel consumption in Thailand has generally been attributed to the lack of domestic upstream production facilities. However, it takes more than just steel production plants to advance the use of steel structures in Thailand. At the moment, the deciding factor in selecting a structural system is still mostly the construction cost. A recent study by the Iron and Steel Institute of Thailand indicates that, when time-saving benefits and salvage values are considered, there is only a marginal difference between costs of concrete and steel structures in Thailand. However, the reality is that most decisions are made based on initial construction cost, over which concrete structures seem to have an advantage. Innovative steel solutions are therefore required in breaking this barrier. In recent years, there has been a surge of innovative steel products ranging from prefabricated or pre-engineered buildings, prefabricated roof trusses, cellular beams, open-web steel joists, buckling restrained braces, and seismic resistant structures. These products will slowly gain recognition and acceptance over time. The challenge lies in shifting these solutions away from individual custom-made projects to mass applications.

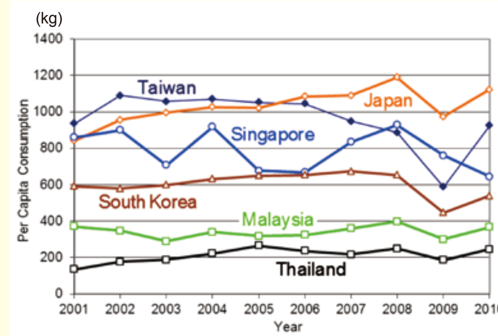

Fig. 1 Crude Steel Consumption Per Capita (World Steel Association 2011)

Research and development into the use of steel structures are therefore very important. Foreign knowledge and technology can not be merely imported. Local construction conditions, customs, and practices require that research and development are needed to create solutions that are distinct and original. The industry must search and develop solutions that fit with local environment. Development of design codes and guidelines that incorporates state-of-the-art knowledge from research and local design practices is important to increase design efficiency. Research and development processes are also vital in training the much needed knowledgeable and qualified professionals. Human resources are always the bedrock for any successful industries. Additionally, the supports from the government can also help increase the number of players in the capital intensive steel producing business.

Without harmonious efforts from all the parties involved, the use of steel structures can only increase at a slow pace. Nevertheless, societal demands are now pushing the construction industry to provide sustainable infrastructure with higher levels of performance and economy (including life cycle costs). This ensures that steel structures will eventually play a prominent role in Thailand's construction industry in the near future. ■

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