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Tomogi-Tsukuri for the Twenty-First Century

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Abstract

Japan has a history of more than a thousand years of solid wooden building construction as exemplified by* Horyuji *Temple and* Todaiji *Temple in Nara. The tradition is also put to use in residential house construction. One of the technologies used is* tomogi-tsukuri. *In this technology, timbers from the same forest are used to make exquisitely accurate structures. However, now that the conservation of forest resources is called for from the viewpoint of environmental protection, it has become extremely difficult to use the technology in the construction of ordinary houses. The development of residential house construction materials by Nippon Steel Corp. such as steel-framed houses aims at creating the* tomogi-tsukuri *for the new millennium, whereby steel materials which are lighter than wooden materials and qualitatively superior, particularly in dimensional accuracy, are used as structural members, sparing valuable wooden materials for parts of which people actually appreciate the feel and appearance.

1. Elegance of Wood-frame Buildings Embodied by Nanpeidai Official Residence

Nippon Steel's Nanpeidai official residence is the Kioi dormitory relocated in December 1989 from Kioi-cho, Chiyoda-ku, Tokyo to Nanpeidai, Shibuya-ku, Tokyo. In the *Edo* era, the Kioi dormitory was the site of the *Edo* residence of the *Owari* clan. In the *Meiji* era, Count Kagawa obtained the land, and a building was constructed there by Shinichiro Okada who designed the *Kabukiza* Theater, among other structures. In 1950, Fuji Iron & Steel, a predecessor of Nippon Steel, bought the building and operated it as the Kioi dormitory. It was relocated to make way for the Kioi Hall.

Photo 1 shows a general view of the Nanpeidai official residence. The Japanese-style building on the left follows the *shoinzukuri* design established in the *Momoyama* era, while that on the right is a British-style building. Both are masterpieces of wood-frame construction in the *Taisho* era.

Photo 2 shows the interior of a second-floor room in the Japanese-style building. The wood-frame members are the *tomogi-tsukuri* type and were sawed in the straight-grain pattern from *Bishu* cypress (*Kiso* cypress) trees at least 700 years old. *Tomogi-tsukuri* refers to the technique of constructing an entire house with wood produced from the same forest. Use of lumber sawed from the trees exposed to the same sunshine and wind conditions provides the same wood grain and tone, and conceals the warp, shrinkage, twist, and other deformation of wood members used. The decorated eave girder of the veranda of the room shown in **Photo 3** is a solid *Bishu* cypress timber 13 m long. The wisdom and skill of joiners are condensed in such finish and trim workings as *ranma* (fanlight), *tokonoma* (alcove), *wakidoko* (side floor), and *tenbukuro* (shelving).

The author, responsible for the work of relocating the Kioi dormitory to Nanpeidai, took pains to restore the work to the original condition. What he saw was the essence of techniques employed to construct a full-fledged wood-frame building with not a single distortion even after 100 years.

2. Why Steel Now?

Whereas there is such a real wood-framed building, many people lost their lives when traditional wooden houses collapsed in the Great Hanshin Earthquake of January 17, 1995. It was very tragic.

Many causes are cited for the collapse of traditional Japanese

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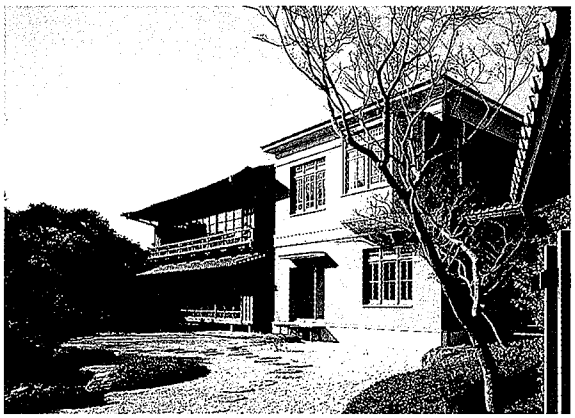


Photo 1 General view of Nanpeidai official residence

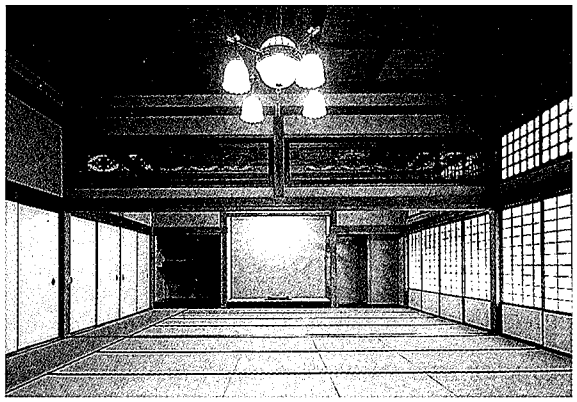


Photo 2 Interior of second-floor room in Japanese-style building in Nanpeidai official residence

Photo 3 Decorated eaves girder in second-floor veranda in Nanpeidai official residence

houses in the earthquake. One is the poor quality of wood structural members used in such houses. The life of lumber is said to the same as that of the tree from which it was sawed. That is, lumber produced from a 1,000-year-old tree can last 1,000 years in usage. Since environmental protection makes it all the more difficult to fell trees in the forests of North America, logs imported to Japan from there are mostly less than 50 years in age and small in diameter. They are not durable enough and are poor in quality as represented by warpage resulting from repeated cycles of drying and wetting.

Steel is a good structural material for residential construction. The smell and warmth of wood is the Japanese culture itself. Valuable wood should be sparingly used in construction members to be touched and seen by people, and steel should be used to support them.

Light-gauge steel shapes made of galvanized steel sheet are the materials that carry wood members. They are lighter than wood, easy to handle, joined with screws in place of nails, and cut well with an electric saw at the site. Homebuilders can handle them as easily as wood. They have high strength and excellent durability, and being industrial products, feature close dimensional tolerances and little change with time. A residential home built by using light-gauge steel shapes as structural members is the *tomogi-tsukuri* of the next century as aimed at by Nippon Steel.

3. Steel-Framed Houses

A house built with structural members of light-gauge steel shapes is the steel-framed house. **Photos 4** and **5** show the general view and construction of a steel-framed house built in Chiba with the

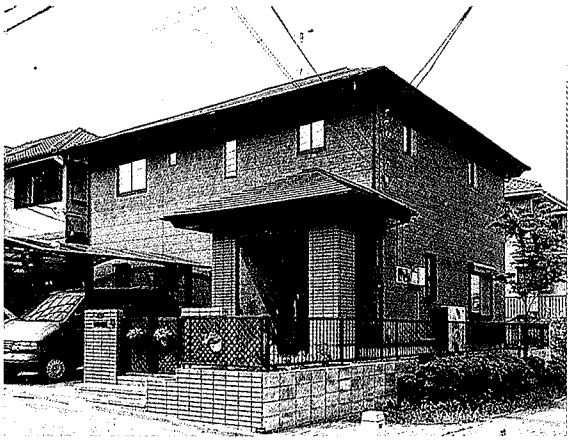


Photo 4 General view of steel-framed house

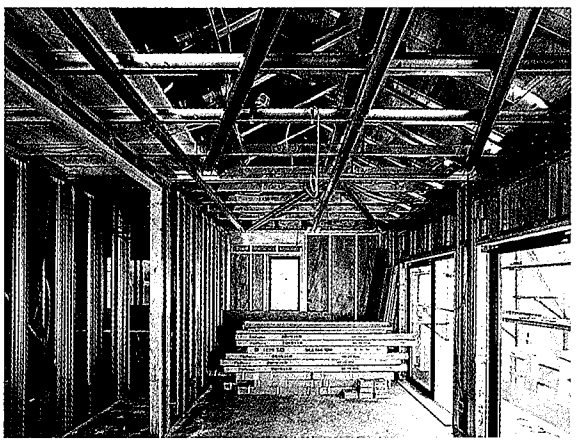


Photo 5 Steel-framed house under construction

aid of Nippon Steel.

Unlike steel-frame buildings and factories, steel-framed houses are similar to wooden two-by-four houses.

Two-by-four is a traditional construction system for houses in North America. Plywood is nailed to a wooden frame with basic dimensions of 2 and 4 inches (actually 38 and 89 mm) to form a wall or floor component. The two-by-four construction was introduced into Japan in the 1970s. Since it won a high rating for its excellent seismic resistance in the Great Hanshin Earthquake, it has rapidly grown and now reaches some 100,000 housing units per year.

Why wood-frame construction? Why two-by-four? The author and his co-workers had many discussions in the early stages of steel-framed house development.

Research on steel-framed houses in Japan began with the formation of the Urban Steel Research Group sponsored by the Iron & Steel Production Division (now Technology Promotion Office, Iron and Steel Division), Basic Industries Bureau, Ministry of International Trade and Industry, and chaired by Sadayoshi Igarashi, Professor Emeritus of the Osaka University. Six steelmakers joined the research group and studied steel-framed houses as one of the group's research subjects. Nippon Steel pushed ahead with the subject as managing company. The development of steel-framed houses has been led by the Committee on Steel-Framed Houses of the Kozai Club since January 1996.

Steel-framed houses started with the replacement of two-by-four wooden frames by building construction steel furrings for walls and ceilings about 30 years ago in the United States. Since President Clinton issued an order banning logging in national forests in 1992, the skyrocketing prices of lumber has accelerated the construction of steel-framed houses, reaching 95,000 units per year in 1997. As more than 90 percent of the American homes are of two-by-four construction, steel-framed houses are steel versions of the two-by-four wood-framed houses.

The majority of single-family houses in Japan are traditional wooden houses as shown in **Fig. 1**. Prefabricated steel-framed houses account for 20%, and two-by-four wooden houses are about 10%. Japan is different from the United States in that single-family houses are constructed by several different methods.

The members of the Committee on Steel-Framed Houses concentrated their discussion on the methods whereby steel-framed houses can be easily designed and built by ordinary homebuilders by making the most of the advantages of light-gage steel shapes that can be handled like wooden members at the site.

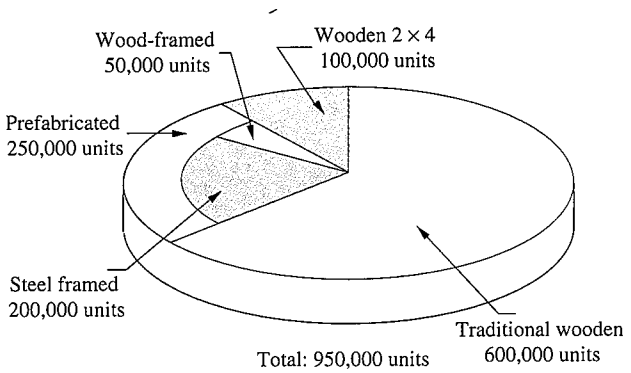
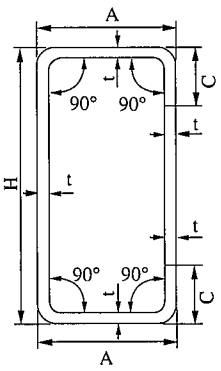


Fig. 1 Single-family housing starts by type of construction in Japan in fiscal 1996



Lipped channels

Name	Dimensions(mm)	
	H × A × C	t
235LCW	235 × 50 × 20	1.2 × 1.6
235LCN	235 × 40 × 20	1.2 × 1.6
184LCW	184 × 40 × 20	1.2 × 1.4
140LCW	140 × 50 × 12	1.2
140LCN	140 × 40 × 12	1.2
100LCN	100 × 40 × 12	1.2
89LCN	89 × 40 × 12	1.0 × 1.2
89LCM	89 × 44.5 × 12	1.0 × 1.2
80LCM	80 × 44.5 × 20	1.2

Fig. 2 Standard for light-gauge steel channels (shape and dimensions)

Steel-framed construction is naturally targeted at traditional wooden houses that account for the majority of single-family dwellings in Japan. Traditional wooden houses are of frame or beam-column construction and use relatively large 90 to 120 mm square columns, for example. Such members call for steel shapes cold-formed from 1.6 mm or thicker hot-rolled steel sheet: for example, general structural square steel pipes (JIS G 3466) or general structural light-gauge steel shapes (JIS G 3350). They are connected by welding or high-strength bolting, which are difficult for wooden housebuilders to handle. Prefabricated steel-framed houses are steel versions of conventional wooden houses.

Two-by-four construction distributes forces between steel shapes and plywood, and has the local buckling of steel shapes restrained by plywood. Light-gauge steel shapes of about 1.0 mm wall thickness and small section can be put to the most effective use in two-by-four construction. Since conventional wooden housebuilders often handle two-by-four construction, we judged that the two-by-four construction they are familiar with is a shortcut to the widespread acceptance of steel-framed houses.

Fig. 2 shows the Kozai Club standard for light-gauge steel shapes. It was our conclusion that the steel shapes should be made to the very same dimensions as two-by-four wood members. Application of the two-by-four wood construction method to steel-framed houses involves several problems. When integrated with plywood, is the life not governed by its plywood? Can a new technique, for example, a damping brace, be introduced? We gave priority to the rapid diffusion of steel-framed houses and elected to adopt the two-by-four construction method. A new steel-framed house construction method that exceeds the two-by-four construction is the next challenge for us to tackle.

4. Hybrid Construction

Besides steel-framed houses, Nippon Steel is devoting attention to hybrid construction. The hybrid construction uses light-gauge steel shapes in some structural members, unlike in steel-framed houses whose structural members are entirely made of light-gauge steel shapes.

Here is introduced an example of hybrid construction for roof framing.

Nippon Steel has jointly developed roofing components (shown in **Photo 6**) with Asahi Chemical Industry as one application of

light-gauge steel shapes in the roof framing of prefabricated steel-framed houses. The framing of Asahi Chemical Industry's decorative roofs was formerly made by carpenters with wood. The new hybrid roofing components were developed to take the place of the wood framing. They are about 50% lighter than wood counterparts, easier to handle, and higher in dimensional accuracy. Steel frame erection workers, not carpenters, can build roof framing. This is expected to contribute greatly to cost savings in housing construction.

The structural members, other than columns and beams, of prefabricated steel-framed houses to support walls, floors, and roofs are still often made of wood. They are studs, joists, and rafters. When you visit a prefabricated steel-framed house manufacturing factory, you may mistake it for a sawmill. Prefabricated home builders are substituting steel for these wooden structural members to improve the productivity of their factories and enable the construction of their homes by workers other than carpenters. Under these circumstances, wooden members are being rapidly replaced by steel counterparts.

Another example of hybrid components in two-by-four wood construction is roof framing developed by Nippon Steel jointly with Mitsui Home (see **Photo 7**). Mitsui Home is also studying the substitution of steel for wood in floors and ceilings. New hybrid two-by-four houses are emerging in this way. These hybrid housing components are expected to see increasing usage by ordinary two-by-four home builders.

These hybrid construction components are widespread in buildings, especially as steel-concrete mixed construction methods like steel-framed reinforced-concrete (SRC) construction and concrete-filled steel tube (CFST) columns. The use of light-gauge steel shapes is expected to accelerate hybridization in residential housing.

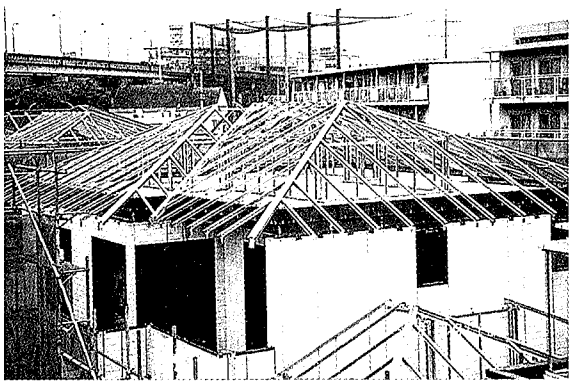


Photo 6 Hybrid construction (jointly developed with Asahi Chemical Industry) in prefabricated steel-framed house

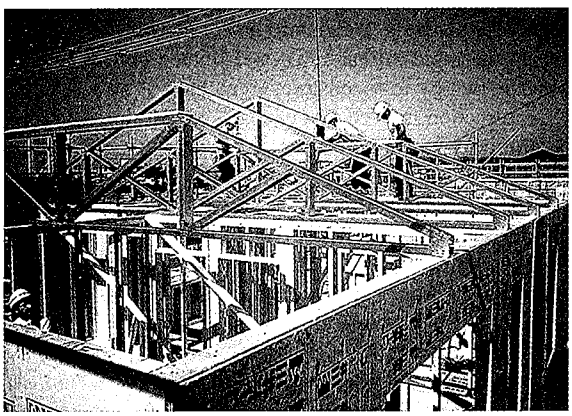


Photo 7 Hybrid construction (jointly developed with Mitsui Home) in wooden two-by-four house

5. Market Development of Light-Gauge Steel Shapes

A technical overview has been presented above of the development of residential building materials targeting *tomogi-tsukuri* in the next century.

The efforts reported here are related to the market development of light-gauge steel shapes launched by Nippon Steel on a massive scale in the 1960s. **Fig. 3** shows the breakdown of domestic steel demand in fiscal 1953 and 1996. In fiscal 1953, civil engineering and building construction combined to account for a mere 10% of the total steel demand and mostly consisted of reinforcing bars, but they now constitute 50% of the total steel demand in Japan. Construction steels owe their present popularity to the effort expended by our precursors at Nippon Steel in developing markets for new steels like wide flange beam and light-gauge shapes.

Light-gauge steels were used for the first time in the last century in the United States and begun to be widely used as structural members for homes, factories, commercial facilities, and barracks (Quonset huts), among other things, during World War II. In Japan, Yawata Iron & Steel (another predecessor of Nippon Steel) started the production of light-gauge steels at Nakanoshima Seiko (present Nippon Steel Metal Products) in 1995. Other steelmakers entered this field thereafter.

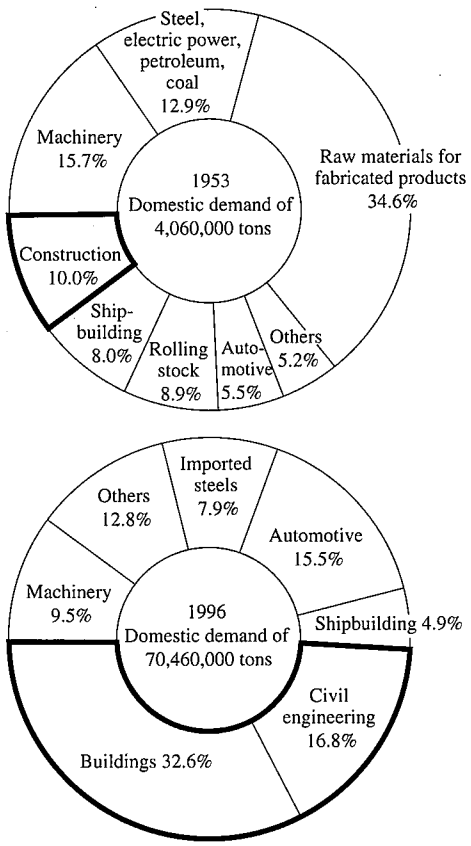


Fig. 3 Changes in domestic steel demand in Japan

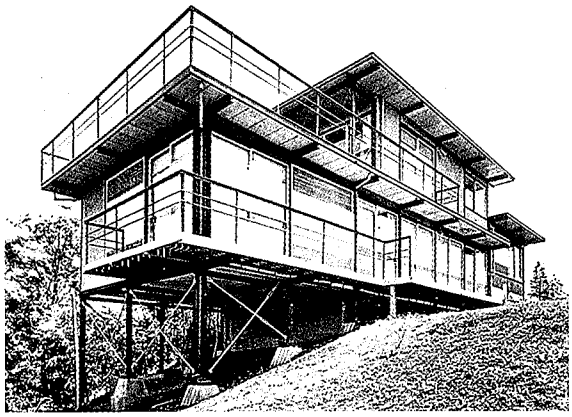


Photo 8 House constructed of traditional light-gauge steel shapes in 1960s

The market development of light-gauge steels targeted residential housing.

Photo 8 shows a house constructed with light-gauge steel framing in the 1960s. Urgent housing issues then were the massive need and noncombustible construction of houses to make up for those burned down by air raids during the war. Prefabricated steel-framed houses arose from this national policy and the need of steelmakers to develop applications for their light-gauge steel products. In those days, the steel companies themselves were engaged in the housing business. (For example, Nakanoshima Seiko operated Econ House Sales, but later quit the housing business as dedicated prefabricated steel-framed home builders rapidly grew.)

Japan had no light-gauge steel standards and design methods then. Steelmakers started their light-gauge steel market development efforts with the development of such standards and design methods, and have since then carried out positive actions to publicize light-gauge steels by such measures as creation of manuals and establishment of training courses.

Today, Nippon Steel is tackling the very same market development with steel-framed houses as was prevalent then. This attempt, however, is different in that ordinary home builders, claimed to number some 150,000 throughout Japan, are taken as targets for sale of light-gauge steel housing components. Unlike big prefabricated home manufacturers, these home builders find it difficult to perform large-scale technology development by themselves. Nippon Steel and other steel producers are building the framework under which they develop steel-framed house construction technology and furnish it to conventional home builders, so that the latter can design and construct steel-framed houses. Nippon Steel is trying to become a headquarters to supply a chain of home builders with products and technologies.

Forty years have passed since the birth of prefabricated steel-framed houses in Japan. Prefabricated steel-framed houses now account for 20% of single-family dwellings. The bulk of housing construction is still carried out by conventional home builders. These home builders came to doubt the earthquake resistance of traditional wooden houses in the Great Hanshin Earthquake, and feel unsure of future management due to the aging of carpenters and other skilled workers, among other factors. The initiative reported here is designed to support home builders with the technical capability of Nippon Steel and other steelmakers, and is expected to make great contributions to the modernization of housing production in Japan.

6. Conclusions

A technical overview of the development of housing construction materials by use of light-gauge steel shapes has been presented above, mainly centering on steel-framed houses. This issue of the Nippon Steel Technical Report (NSTR) also describes the use of fire-resistant steels in the framing and roofing of residential houses and the development of zinc-magnesium alloy-coated sheet steel (trademarked Dymazinc) for construction applications.

Buildings have been symbols of power and high technology since the era of ancient Egypt. A very tall spire of a Gothic cathedral. Great Buddha Hall of the *Todaiji* Temple. These very tall or large buildings astonished and touched people, but they lived in shabby houses built with low technology.

The Great Hanshin Earthquake called the quality of traditional wooden houses and the capability of conventional home builders into question anew. The initiative of Nippon Steel reported here is intended to renovate the framework of housing production itself with light-gauge steel shapes. It aims at *tomogi-tsukuri* in the next century with steel of the highest quality in the world.