

Design and Construction of Steel-Structured Houses and Future Efforts

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Abstract

Presented here are the footprints of ingenuity and improvement activities carried out to date in the fields of the design and construction of steel-structured housing. In parallel with efforts for four-story steel-structured housing, we planned room layout based on basic modules, developed residential building layout plans, made design improvements for construction labor-saving, focused on the quality, and designed construction methods, tools, etc. that hold promise for improvement.

1. Introduction

Steel-structured housing is constructed with thin steel sheet of light-gauge section steel produced by cold-forming 1 mm-thick galvanized steel sheets as the frame material similar to the frame material of the two-by-four wooden construction method (frame wall construction method). The first steel-structured housing was built with US assistance as part of the temporary dwellings constructed for the restoration after the Great Hanshin Earthquake in 1995. In 2000, in the revised Building Standards Law enacted in 2000, the technical standard pertaining to steel-structured housing was established and is still observed to the present day¹⁾.

The first project that Nippon Steel & Sumikin TEXENG. Co., Ltd. (NS-TEXENG) designed and constructed with the NS Super Frame System (hereinafter referred to as the “NSSF Construction Method”) is the Takayokosuka company apartment house built in 2006. During the ten years that followed, the present design and construction technologies were established after the accumulation of devices and improvements that developed through the challenges faced in various projects.

The following introduces the actual state and improvement efforts, as well as subjects for future consideration.

2. Footprints of NSSF Construction Method

The development of the NSSF Construction Method was started at the Takayokosuka company apartment house (Tokai City, Nagoya Prefecture) that was completed in 2006 (Photo 1). The construction

method was then developed through the actual design and construction of the company apartment house and dormitories of Nippon Steel & Sumitomo Metal Corporation and its group companies (Table 1); through the improvements made by the design standardization of the dwelling floor plan, stairways, corridor, balcony; and through improving the construction efficiency. This has led to the establishment of the current NSSF Construction Method. Among such activities, the efforts to secure the heat insulation performance in cold regions and the efforts to develop housing furnished with protective measures against earthquakes and disasters have greatly contributed to the enhancement of the technology.

Recently, development of the NSSF Construction Method for



Photo 1 Achievement of steel framed house (Takayokosuka company apartment)

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Table 1 Result of steel-structured housing

| Year | Main project | Plan summaries |
|------|---|---|
| 2006 | Takayokusuka AP | 3-building (78 room), 3-storied house |
| 2007 | Aishin Nursery, ex. | Large space |
| 2008 | Tokoshiro Dormitory, ex. | 1-building (60 room), central corridor type, using sound insulation floor |
| 2009 | Kamaishi AP (NSSMC) | 2-building (60 room), using ALC to balcony |
| 2010 | Ooike AP (NS-Logistics Co.), ex. | Improvement of staircase |
| 2011 | Kamaishi AP (NS-Logistics Co.), ex. | Countermeasure for the cold temperature area |
| 2012 | Kamaishi Restoration Public Housing (I-stage) | 4-restoration building (54 room), evaluation of dwelling performance |
| 2013 | Futsu Dormitory (NSSMC) | 2-building (99 room), certification of disaster control (tsunami) |
| 2014 | Muroran AP (Cooperation Company), ex. | |
| 2015 | Akenokita AP, ex. | 4-storied house |

AP: Apartment

**Photo 2 Achievement of steel framed house (Akenokita company apartment)**

actual application to a four-story residential building has been promoted by Nippon Steel & Sumitomo Metal, NS Hi-Parts Corporation and NS-TEXENG, and it was established as an appropriate method at the completion of the Akenokita company apartment house (**Photo 2**) in November 2015.

3. Planning of NSSF Construction Method

3.1 Focal point in developing floor plan

3.1.1 Floor plan composed of basic module

As the structural panel (910 mm=1.0P) produced in SHAKU dimensional units, the traditional Japanese unit of length, is used, the walls are laid out based on the width of the basic module being 455 mm (=0.5P). To avoid unnecessary use of specially-shaped manufacturing panels, reinforcing panels and complicated detailed structure, which affect the cost and construction term, the vertical wall frame panels and the floor panels have to be arranged effectively in accordance with the module. Therefore, in developing the floor plan, it is necessary for design engineers, structural engineers and equipment engineers to confer in advance to develop the residential building plan and the dwelling floor plan based on the module.

3.1.2 Dwelling floor plan with focus on layout of structural panel

In this construction method, structural provisions for the layout of the structural panel and the opening of the structural panel are strictly set forth. Accordingly, a study on the requisite size of load-bearing walls and the location of the aperture for equipment has to be conducted in parallel with the development of the basic dwelling floor plan in order to prevent reworking and modification of the plan.

3.2 Example of improvement efforts for developing dwelling floor plan

3.2.1 Plan of external corridor

Conventionally, an overhang slab structure such as that of the corridor and the balcony was planned based on a steel frame structure and the required space was provided. However, in this case, if the overhang length of the floor increases, the floor-fixing force increases as well. To address this problem, the dwelling building, the corridor floor and the balcony floor are integrated into a single panel structure in the NSSF Construction Method, and the following improvement effects were obtained by installing the front-end supporting wall.

(1) Wide exterior corridor in practical application

Use of the corridor for a plurality of purposes (arrangement of community space)

(2) Thinned floor panel slab

The step height difference between the inside floor and the outside floor is eliminated and a window opening for directly removing dirt and dust from the room was realized.

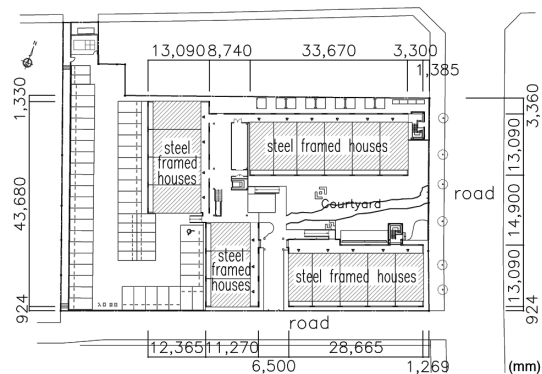
(3) Securing the water drainage slope

The water drainage slope is secured by the thinned floor panel.

3.2.2 Plan of \sqcap shaped residential building layout

It is structurally impossible to install the cantilever slab for the projected corner structure using this construction method due to the absence of the floor panel. Therefore, when residential buildings are to be connected in the form of a \sqcap shaped layout, the freedom of design is restricted. In this case, at the front end of the cantilever type slab, the front end supporting wall is installed. By connecting the exterior corridor/common use corridor having a thinned floor slab with the connecting corridor (steel frame structure) via an expansion joint metal hardware installed at the connecting section, the design was improved to allow connection of the residential buildings without floor height difference. Thus, the design of the residential building in the \sqcap shaped layout was realized.

In the restoration public housing in Kamaishi (**Fig. 1**), the ground plan of the \sqcap shaped residential building layout that surrounds a courtyard was employed owing to this improvement and

**Fig. 1 Ground plan of the restoration public housing in Kamaishi**

contributed to the realization of a community courtyard space for senior citizens.

3.3 Focal point in developing structural plan

For the three-story residential building built using the NSSF Construction Method, the regulations for obtaining public approval regarding the structural aspect have been revised several times to date, and structural design conforming to the revision has been made. This section outlines the focal points and the countermeasures based on selected examples of the designs of three-story dormitories and the company apartment house.

3.3.1 Focal point in developing wall layout plan

There are three types of structural wall.

Load-bearing wall: Structural wall that bears a vertical load (self-weight, others) and horizontal load (earthquake, wind and others)

Supporting wall: Structural wall that bears a mainly vertical load (self-weight, others)

Miscellaneous wall: Wall structured of light-gauge steel frame as the base, which does not bear either a vertical load or horizontal load

Furthermore, the following three types of load-bearing walls are provided depending on the surface member material affixed to either side of the frame material (Table 2). Thus, there are many types of wall structure and an optimal plan needs to be developed with the appropriate combination, taking into consideration the details in combining the walls and/or the construction performance. The focal points and the countermeasures are as follows.

(1) Layout of the load-bearing wall

In the dwelling unit plan, as large windows with sashes are planned generally on the wall facing the corridor and the balcony, in many cases, sufficient load-bearing walls cannot be secured. In this case, sufficient load-bearing walls are secured by providing double load-bearing walls in the dwelling. However, when the use of numerous high-performance load-bearing walls (double wall) is planned, as the force acting through the hardware and the bolt that connect the upper story and the lower story exceeds their allowable load-bearing capacities, structural problems are caused. Consequently, the floor plan has to be revised due to the increase in the number of load-bearing walls. Therefore, attention is required when developing the floor plan.

(2) Layout of the supporting wall

As the aperture to be opened on the load-bearing wall is limited quantitatively, it is necessary to discuss the aperture position with the equipment engineers in the early stage of planning. The wall layout needs to be developed incorporating the plan of the route of the piping and the duct. When the aperture area exceeds the limit, the subject wall is to be used as the supporting wall with an additional load-bearing wall being installed elsewhere to secure sufficient load-bearing walls.

(3) Layout of the miscellaneous wall

There are many cases wherein the wall layout of the plumbing section such as the toilet, unit bath, taps etc. cannot conform to the basic module because of the need to secure the required amount of

space and the arrangement of equipment. In this case, the requirement for sufficient load-bearing walls is studied and the wall layout is to be planned such that miscellaneous structural panels are used as the partition.

(4) Layout of the foundation

In the foundation, as the underground beams have to be laid out under the load-bearing wall and the supporting wall, by employing a double load-bearing wall appropriately and thereby reducing the load-bearing wall foundation line length, and by minimizing the foundation arrangement, higher workability in construction work, easier maintenance and higher economy are obtained.

Currently, none of the requirements described above are being conducted for each plan; therefore, efforts are being made to devise a standard pattern for optimal function.

3.3.2 Design with consideration given to labor reduction in construction

In the panel assembly work, construction performance is greatly affected by the structural design concept. Therefore, the problems in the construction work and the points to be improved are continually fed back to the design and the design is revised so as to provide a safe and lower-cost plan. In the following, selected from actual past applications, ceramic-based surface member material on both sides and the efforts for the improvement in the structural panel connection are introduced.

(1) Ceramic-based surface member material on both sides

A load-bearing wall with ceramic-based boards affixed on both sides of the panels is a high load-bearing wall (20% higher load-bearing capacity than conventional load-bearing walls), and has the advantage of shortening the actual length of the load-bearing wall. However, as the ceramic-based surface member material is hard and large, the construction workability is poorer and costlier when compared with the use of gypsum-board. Therefore, its use should be avoided to the extent possible for effective labor reduction. In the case of employing a load-bearing wall with ceramic-based surface member material, the overall length of the load-bearing wall on the first floor is to be made as long as possible; the use of the load-bearing wall on the upper floors (second floor and above) is to be minimized to the extent possible, wherein sufficient load-bearing walls are to be secured, while maintaining the balance strength ratio (rigidity vs. the number of load-bearing walls) on each floor.

(2) Panel connection section (hardware mounted on-site)

The hardware mounted on-site is arranged at the panel connecting position where the load-bearing walls are connected to each other in the shape of the letter L or T. In recent years, as the strength of load-bearing walls has increased and the sheet thickness of the frame material of the load-bearing wall end has become larger, the fixing work of the mounting bolt within a confined space has become troublesome. As a countermeasure, for the case of a load-bearing wall being connected to another load-bearing wall perpendicularly with the hardware, the design has been improved so as to reduce the on-site panel-connecting work by arranging the hardware of the load-bearing wall at a position 0.5P (455 mm) apart from the panel connecting position via the supporting wall, enabling the mounting of the hardware at the manufacturing factory (Fig. 2).

4. Architectural Equipment

Steel-structured housing features “a panel structure that integrates thin steel sheet light-gauge section steel and structural surface member material,” “fire protection performance provided by a membrane, (integration of structural surface member material and

Table 2 Composition of structural panel

| Obverse | Reverse |
|---------------------|---------------------|
| Ceramic-based board | Ceramic-based board |
| Ceramic-based board | Gypsum board |
| Gypsum board | Gypsum board |

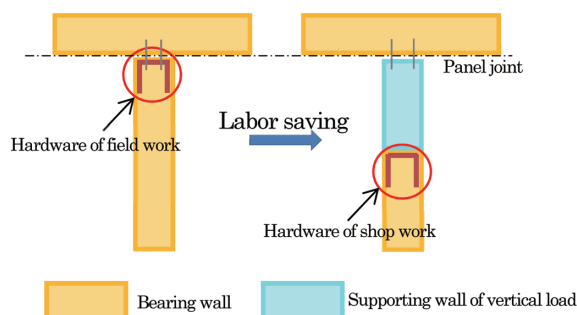


Fig. 2 Labor saving of connecting panel in construction site

coating material),” and “shortening of the on-site construction term by prefabrication in a factory.” In order to strengthen our competitiveness, it is necessary to fully promote such features and the following efforts are being made for each of the aforementioned components.

(1) Plan (design)

A detailed study is being conducted on the conditions that satisfy the restrictions on the structural surface member material and the membrane such as the restrictions on the aperture opening and the panel layout.

(2) Construction aspect

A study is being conducted on the unitization of the cable wiring and piping, prefabricated built-in box piping in the factory and the in-factory aperture opening on the structural surface member material to further reduce the volume of on-site construction work.

(3) Maintenance control

A study is being conducted on a plan that enables renewal and maintenance of piping etc. without damaging the inside of the dry wall panel and the floor panel, which are important components for fire protection and the structure.

In the following, examples of the outcome and subjects now under study are introduced successively.

4.1 Detailed conditions for satisfying restriction imposed on structural surface member material and membrane

4.1.1 Standard for planning aperture for equipment

Restrictions are imposed on each structural panel (1P) of the steel-structured housing pertaining to aperture, and “restrictions on structural load-bearing force” and “restrictions on securing fire protection” must be satisfied. For the restrictions pertaining to the structural load-bearing capacity, the number of apertures, the distance between apertures and the upper limit of the aperture dimensions are specified for each panel; for the restrictions pertaining to fire protection, the upper limit of the dimensions of each aperture is specified.

Furthermore, there are restrictions on securing the load-bearing capacity where the aperture on the 0.5P width board in the load-bearing wall is strictly prohibited and the exterior ceramic-base surface member material and the indoor side gypsum board must conform independently. Accordingly, in the case of a wall that is continuous in the direction of openings with apertures, as a detailed study is necessary, creation of a detailed diagram indicating the standard layout of the apertures was undertaken and two standard specifications for a family type dwelling (2LDK type) and a single persons' dwelling (one room type) were developed.

Furthermore, as the panel layout in the standard diagram was developed based on a “floor plan that strictly prohibits the 0.5P structural panel” and the “panel layout plan based on a panel consisting of the exterior ceramic-base surface member material and the

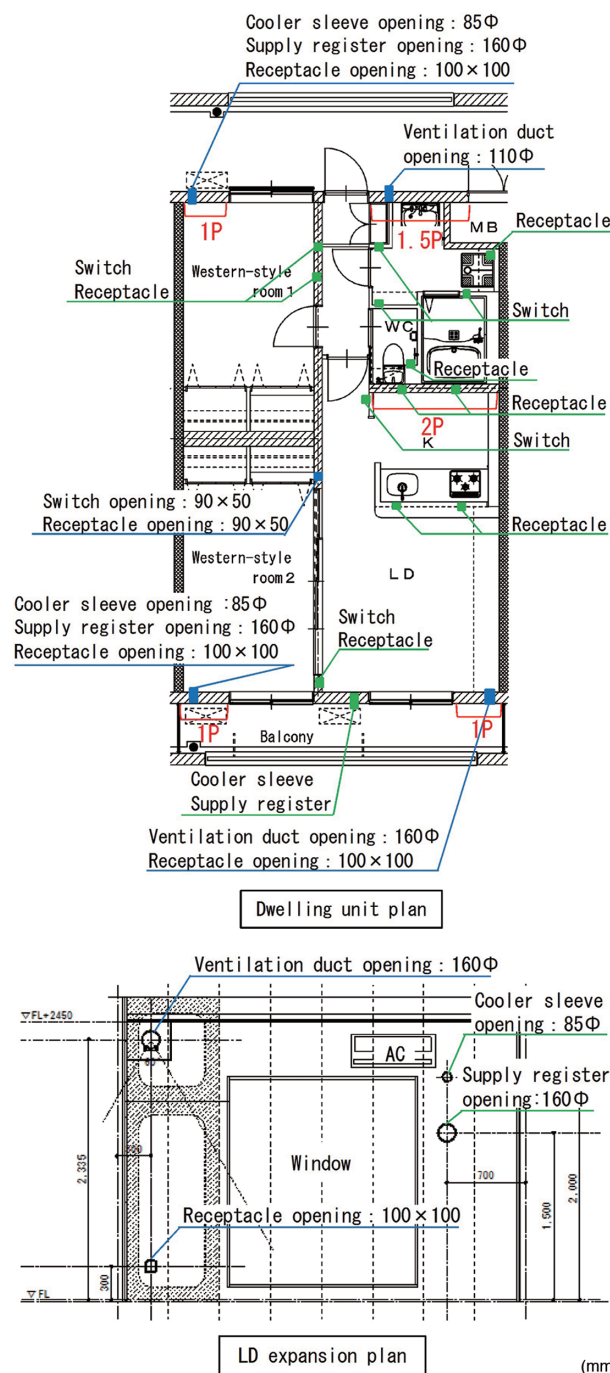


Fig. 3 Road map of aperture for the family

interior gypsum-board integrated into a single panel,” a standard plan was developed through the joint efforts of the industrial design staff, structure and equipment design staff (Fig. 3).

4.1.2 Detailed conditions for securing fire protection

This construction method provides structures with one-hour rated fire resistance performance. Specifically, this structure is provided with a fire-resistant membrane consisting of a ceramic-based siding material (exterior material) excellent in fire-resistance performance and a gypsum-board siding material (interior material). Accordingly, setting an aperture or a hole on the membrane for laying pipes of equipment and cables weakens the fire resistance perfor-

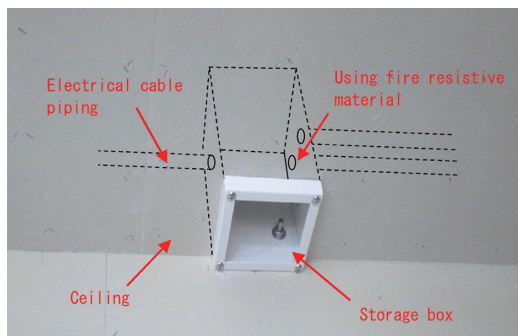


Photo 3 Storage box for communicate cable

mance and therefore, it is necessary to secure sufficient performance by filling the gap with a fire preventive putty material. In the construction stage, the performance is secured by applying the fire-resistance measures to the penetrating hole part. As for the measures for the penetration part of the floor panel membrane for the communication cable that is installed after the delivery, to secure the fire-protection function in future as well, a built-in cable storage box is installed, for which a detailed study is underway for application of the fire resistance treatment (Photo 3).

4.2 Unitization and strengthening prefabrication in manufacturing factory to shorten construction term

In the field of architectural equipment, shortening the construction term and reducing the construction cost by taking advantage of prefabricating panels in a factory are matters to be addressed. The on-site labor reduction is investigated from two aspects: one is the unitization method wherein equipment members are produced in a factory, and the other is the prefabricated built-in method wherein the equipment members are built into the panel produced in the manufacturing factory.

4.2.1 Unitization method

In the construction of steel-structured housing, as the structural panels are transported to the construction site and erected in succession, compared to reinforced concrete housing, it is difficult to secure the term for the wiring of the electric outlet of electric lights within a dwelling unit before the start of the interior finishing work. However, as the shortening of the electrical work term is directly linked to the shortening of the entire construction term, in order to reduce the amount of on-site work, the wiring work was conducted by using unitized cable produced in the factory in advance (Photo 4, Fig. 4). Although employment of unitized cable is costly, the merits of the expected reduction in labor cost and the shortening of the construction term far outweigh such cost. Presently, efforts are being made to unitize not only the cable, but also the water-supply and drainage pipes. Once the advantage of this has been clarified, standardization will be considered (Fig. 5).

4.2.2 Prefabricated built-into panel method

Aiming at reducing the on-site work, the prior installation or prior application in the factory of the electric wiring tube and storage box, supporting members, opening of holes for equipment, fire protection material and so forth was studied. If possible, it is expected to yield a large labor reduction in construction work. Presently, although it is still at the stage of experimental study, the subject will be investigated with the aim of realization in future.

4.3 Consideration of future equipment renewal and maintenance

In the countermeasures of regulations pertaining to the promo-

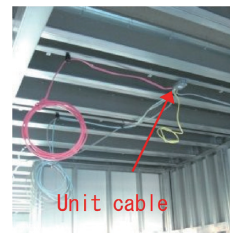


Photo 4 Unit cable

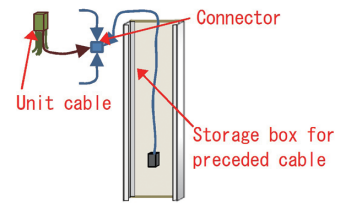


Fig. 4 Image of preceding panel

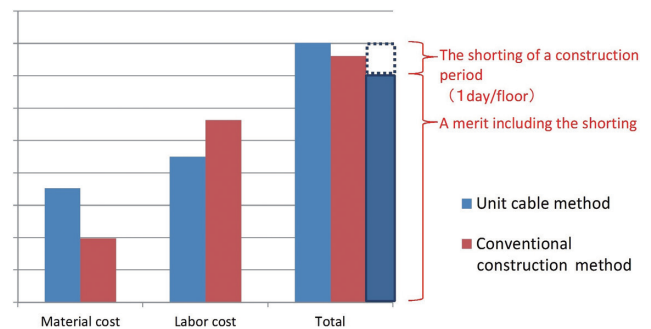


Fig. 5 Comparison of the merit using unit cable

tion of securing the quality of housing, steel-structured housing has obtained the highest rating of Grade 3, with a durability of 75–90 years. Comparing the high durability of the housing, the durability of architectural equipment is only approximately 15–20 years, although this is longer than in previous years. Accordingly, as equipment renewal and maintenance are inevitable, the study and details of the equipment plan that enable the equipment renewal and maintenance without damaging the structural surface member material and the membrane will become necessary.

In particular, when renewing the equipment, as devices for preventing erroneous work of contractors who are not familiar with the restrictions of the steel-structured housing are necessary, a study was conducted on the areas where maintenance needs or the renewal of equipment is expected.

(1) Within the dwelling unit

When the sanitation piping is renewed within a dwelling unit, to prevent damage to the structural wall through which many equipment pipes are run, integration of the plumbing equipment, optimizing the layout of the pipe shaft, and employment of a double wall around the piping space are investigated.

(2) Common use section

A pit is provided under the floor so that the maintenance and the renewal of the common use piping can be performed with ease. To prevent damage to the membrane of the corridor floor at the time of renewal of the common use cable, application of a dual ceiling (for maintenance purposes) is investigated.

5. Construction

The NSSF Construction Method consists of a series of work processes from developing the panel diagram, manufacturing of the panel in the factory (hereinafter referred to as the “framer”), on-site assembly and the interior and exterior finish work. This chapter introduces the control and the handling method of the device and improvement in the respective processes of the entire construction process.

5.1 Manufacturing of panel

5.1.1 Preparation of panel diagram and check

The panel diagram is developed by the framer and checked and revised by the sections concerned (design, manufacturing, construction) (Table 3), and then manufacturing of the panel is started. The process of checking is important to prevent delays in the schedule due to lack of wall load-bearing capacity, deterioration in quality and the occurrence of reworking.

5.1.2 Manufacturing and shipment of panels

Panels are manufactured in the order of their assembly after the acceptance inspection of the material and shipped after the self-inspection of the framer and the intermediate inspection of the prime contractor (Fig. 6). The shipment volume is determined, taking into consideration the order of the assembly of the panels and the volume of the assembly work in a day. Upon shipment, efficient shipping operation by effective loading of the panels onto transportation trucks (loading style) contributes to the smooth progress of the entire schedule.

Accordingly, to eliminate loss in the effective loading space due to loading of the panels onto the truck cargo bed in an inclined shipping position, which has always been problematic, a frame for exclusive use for holding the panel in a vertical posture was manufactured and installed on the truck cargo bed, thus solving the problem. As a synergy effect of the loading in the vertical posture with the frame, the damage of panels (damage at the lower edge corner) caused during the transportation in the conventional manner in the

Table 3 Panel inspection check list

| Item | Contents |
|--------------------------|--|
| Panel layout | Bearing wall layout (wall penetration sleeve) |
| Bearing wall | Comparison of the drawings |
| Ceramics face material | Comparison of the drawings |
| hardware | Position and size |
| Throating sash (outside) | |
| Window opening | Effective size |
| Non-structural wall | Fixed |
| Sleeve | Position and size |

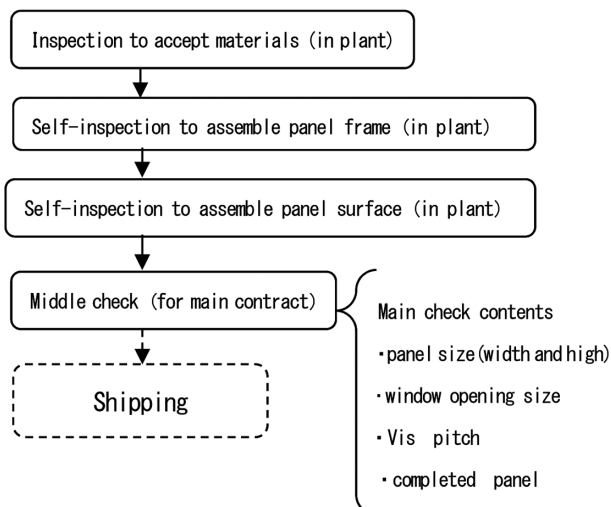


Fig. 6 Inspection flow

inclined posture was prevented, and the pre-assembly in the factory of the “supporting wall” and the “lintel,” which had been shipped separately, has become possible, thus shortening the assembly term.

5.2 Foundations

5.2.1 Measures for improving anchor bolt installation accuracy

In the panel assembly work, the installation accuracy control of the anchor bolt (hereinafter referred to as “AB”) is particularly important from the viewpoint of quality and schedule control. Three control points and the methods thereof are described below (Photo 5).

(1) Preventing interference with the reinforcing bar in the underground beam

The NSSF Construction Method is characterized by the installation of a number of ABs on underground beams, and preventing interference with the reinforcing bar in this position is important for improving the installation accuracy. By drawing the layout of the reinforcing bar in the underground beam on the working diagrams of the anchor frame (hereinafter referred to as AF) and the AB, preventing mutual interference and the interference of the position of the coupling of the main reinforcing bar in the underground beam with the short AF column is confirmed in advance, and the construction plan is decided. In the marking operation, the position of the respective member materials was marked for clear identification and interference could be prevented.

(2) Securing AF material fixing strength

In the concrete work, prevention of the movement and/or deformation of AF during the concrete work is very important from the viewpoint of installation accuracy control. When fixing AF with bolts on the flattened concrete surface, the thickness of the flattened concrete was increased more than was planned as a measure for enhancing the fixing strength. With this, the strength to withstand the vibration and shock imposed during the construction work was secured and the accuracy of AF after installation was maintained.

(3) Assembling AF

AF is assembled on the flattened surface of the underground beam. On the upper surface of the angle section steel that is fixed across the upper part of AF (an AF forming member), the AB position is marked and the AB through-hole (bolt diameter+1 mm) is opened, and then AB is set. The lower end of AB is fixed to the angle section steel that is fixed across the lower part of AF (an AF forming member) with the U-ring, and the lower end of AB is fixed. This process is used to prevent deterioration in the accuracy due to construction-caused factors (shock and others) (Photos 6, 7).

5.2.2 Efforts for concreting of earthen floor

As the wall panel of the first floor is assembled on the concrete covering the earthen floor, the flatness accuracy of the upper surface



Photo 5 Panorama view

of the concrete covering the earthen floor affects the assembly accuracy of the panel. Therefore, the upper surface level is controlled to an accuracy of -5 mm at the panel assembly site, and moreover, before the assembly of the panel, the level is adjusted to $\pm 2-3$ mm with mortar or no-shrinking mortar. With the improved assembly accuracy of the wall panel on the first floor, the assembly quality of the upper floors is secured and the construction schedule is controlled to proceed smoothly.

5.3 Assembly of panel

The panel assembly method is selected from the following two methods depending on the site conditions and the heavy machine arrangement plan. Furthermore, in the assembly work, the panel assembly accuracy is secured by using a “specialized tool for modification” etc. (Photo 8) and the final tightening of AB is controlled with the degree of nut rotation and the torque value.

(1) One-way construction method

A method wherein a residential building is constructed by assembling panels of a dwelling unit, securing accuracy, and the

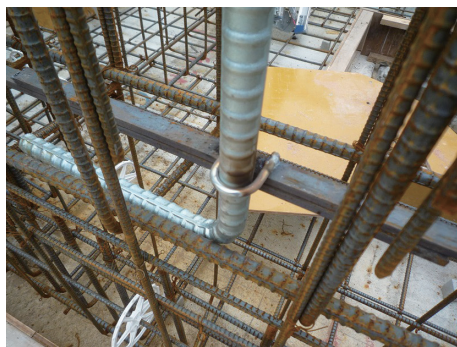


Photo 6 Fixed by U-ring



Photo 7 Assembled frame

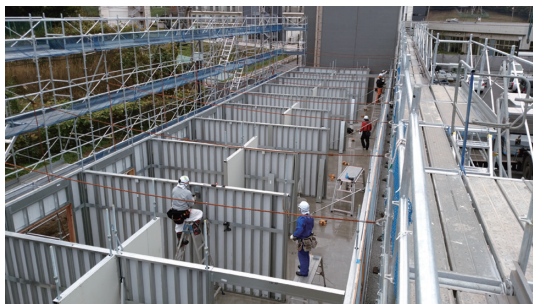


Photo 8 Modification by the specialized tools

dwelling unit next to it is constructed sequentially as the next step.

(2) Prefabricated peripheral construction method

A method wherein dwelling units are formed by assembling the peripheral panels of the residential building antecedently and by assembling the partition section at a later stage.

6. Evaluation of Housing Performance

The design of public housing must conform to the prescribed grade of the “Designed house performance evaluation.” The NSSF Construction Method has acquired the “Recognition by special evaluation method” for the grade pertaining to the deterioration countermeasures, and the design is promoted based on this recognition. The following presents actual examples of a design satisfying the grade requirements pertaining to the energy-saving measures and elderly assistance measures.

6.1 Correspondence to Grade 4 of energy-saving measures

6.1.1 Efforts for conforming to criteria of thermal reflux ratio of peripheral shell

Grade 4 of the energy-saving measures (equivalent to 2013 criteria) demands higher peripheral shell performance as compared to Grade 3 (equivalent to 1992 criteria), and particularly in cold regions, the opening must have high heat insulation performance.

The restoration public housing in Kamaishi is an apartment house situated in a cold region and by employing a floor plan with an exterior corridor on one side, utmost attention was paid particularly to the heat insulation performance of the doors of the meter box (hereinafter referred to as “MB”). In performance evaluation of the house design, the heat insulation performance of doors on the external wall heat insulation line must conform to the criteria. In the NSSF Construction Method (exterior heat insulation construction method), as the exterior wall heat insulation line becomes the external wall line facing the corridor, openings such as the entrance and MB doors require a heat intercept structure. In the case of the MB door in particular, the general design is that openings for supply and exhaust gas piping of a gas powered hot water heater are set in the upper part of the door. However, this does not satisfy the required performance. As countermeasures, a hot water heater with an extended supply and exhaust gas piping are employed and the supply and exhaust gas piping holes are opened on the external wall surface other than the MB door to satisfy the heat insulating performance grade. Considering the possibility of water leakage to the lower floor at the time of the renewal of meters and/or piping in future, a rising water-flow-prevention wall with waterproof coating was set up to the height above the lower end of the door. As further improvement measures, a study on the installation of MB outside the exterior wall heat insulation line is underway.

6.1.2 Correspondence to thermal bridge

As the NSSF Construction Method is of the external heat insulation type, the insulation is structured so as to prevent the insulation deficiency that develops due to the penetration of the floor through the external wall provided with the interior heat insulation. However, the exterior corridor and the balcony sections on the first floor are structured in such a way as to allow the reinforced concrete floor to penetrate through the external wall, and therefore, the formation of a heat bridge is a genuine concern. Accordingly, to reinforce the insulation on the first floor, insulation finished with heat-insulating mortar etc. is provided to the heat bridge region on the first floor in the dwelling unit. To this end, there are two types of specification: one is the “direct heat-insulating mortar casting” and the other is the “polyurethane foam spray + mortar casting,” either of which is se-

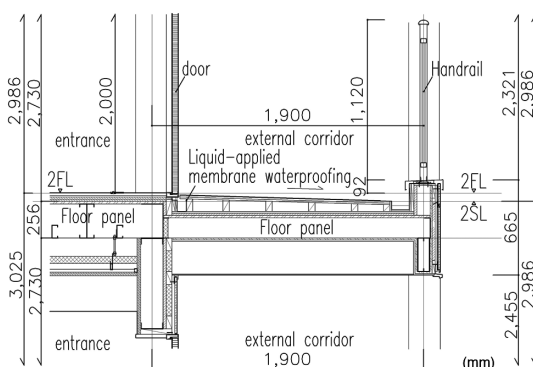


Fig. 7 Detail of the main entrance

lected considering the construction schedule. In whichever case, sections other than the heat-insulation-reinforced sections require additional concrete casting on the floor or mortar casting over the entire range to eliminate the step produced by the heat-insulation reinforcement.

6.2 Correspondence to Grade 3 of elderly assistance measures

For Grade 3 elderly assistance measures, a standard is set for the step height on the floor, and within the dwelling unit, steps on the corridor and in the dressing room/wash room are not allowed by the standard. Accordingly, in the areas concerned, the floor panel drop-in method of lowering the floor panel in the plumbing area only, or the fully double-floored method is employed. Furthermore, in the NSSF Construction Method, although providing a step on the floor panel is difficult, the method corresponded to the standard of the height difference between the floor level of the entrance and that of the outside of the entrance being 15 mm or less by “thinning the exterior corridor floor panel.”

Furthermore, in order to correspond to the standard of the height difference between the doorsill and the entrance dirt floor being 5 mm or less, the entrance doorsill needs to be embedded. In this case, as the outside floor and the doorsill interact on a plane and sealing becomes a problem, the deterioration of the waterproof performance of the doorsill also becomes problematic. Therefore, as a countermeasure, a waterproof paint coated receptacle is installed below the doorsill to prevent the ingress of water (Fig. 7).

7. Efforts for Earthquake Countermeasures

In the Great East Japan Earthquake, although the residential buildings constructed by NS-TEXENG (two buildings were built and four buildings were designed and built) were struck by the earthquake with an intensity equivalent to 6 in Kamaishi City in Iwate Prefecture, there was no structural damage, thus confirming their high performance as earthquake-resistant structures. Examples of earthquake countermeasures for structures built using the NSSF Construction Method are introduced below.

7.1 Efforts for restoration public housing in Kamaishi

Immediately after the Great East Japan Earthquake on the 11th of March 2011, construction of the restoration public housing was prioritized as early as possible for the earthquake victims who had been living in temporary housing. The major advantage of the short construction term of steel-structured housing was fully exhibited as expected. The design was started in April 2012, the construction was started in October of the same year and the housing was delivered to Kamaishi City in March 2013 after a short 5.5-month construction term. The housing attracted attention from everywhere as the first



Photo 9 Restoration public housing in Kamaishi

restoration public housing, and at the same time, the steel-structured housing acquired the first housing performance evaluation conforming to the public housing specification (Photo 9).

7.2 Efforts for tsunami evacuation building

In the earthquake, a large number of wooden structures were severely damaged by the tsunami (outflow and collapse). However, the two-story residential building built in Otsuchi City in Iwate Prefecture using the NSSF Construction Method remarkably escaped any permanent deformation despite the external wall being smashed by floating wreckage and heavily damaged. It was thus confirmed that the structure can withstand a tsunami with a water depth of 5.5 m²). In November 2011, the Ministry of Land, Infrastructure, Transport and Tourism released the “Supplemental information pertaining to the design method of structures, from the aspect of safe structural load-bearing capacity,” and revision of the “Guideline pertaining to tsunami evacuation buildings and the like (Cabinet Office)” formulated in 2007 and the provisional guideline pertaining to the structural requirements of evacuation buildings and the like were formulated.

The dormitory in Futtsu City completed in 2013 is situated about 500 m inland from the coast. To meet the request that the building be designated as a tsunami evacuation building for neighborhood residents in the event of a tsunami, the structural design taking tsunami force into consideration was investigated. The tsunami force was calculated based on the aforementioned provisional guideline and the assumed water depth of the tsunami was determined based on the hazard map of Futtsu City. The following three subjects were studied.

- (1) Comparison of the horizontal load-bearing strength retained by the building vs. tsunami wave force
- (2) Study on overturning and sliding of foundations due to floating force of wave
- (3) Study on the vertical frame material of the external wall subject to tsunami directly and AB that bears the horizontal force

The results of the studies showed that the exterior wall vertical frame requires double the sectional strength of the conventional type. However, regarding the entire building, the tsunami wave force was equal to or less than the earthquake force, and therefore, the design based on the conventional number of load-bearing walls was adopted.

8. Efforts for the Development of Four-Story Residential Buildings

For the creation of four-story residential buildings using the method, joint development was started in March 2013 with Nippon Steel & Sumitomo Metal and NS Hi-Parts. NS TEXENG was mainly responsible for design of the foundations, architectural equipment, finishing work, study on the construction method, details of the various connections in the building and study of the cost. At the

Table 4 Check list for the experiment buildings

| Item of trade | Contents |
|----------------------|--|
| Foundation work | Quality control of AB (AB quality standard and detail of reinforcement) |
| Panel work | Inspection standard of member (hardware size, steel plate size and weight check) |
| Panel erection | Performance confirmation of hauling equipment inspection standard of panels Scheme of execution (torque management ex.) |
| External finish work | Detail of furring strips |
| Interior finish work | Detail of the finish |
| Utility work | Detail of equipment |

final stage of the development schedule, a trial residential building was built on the premises of the Plant Engineering and Facility Management Center in Kimitsu City, Chiba Prefecture, and verification on the actual base was conducted. Upon verification, a checklist (Table 4) was devised, problems were extracted and detailed solutions provided, and the verification was completed in October 2014.

In February 2015, a four-story company apartment house was ordered by the Oita Works of Nippon Steel & Sumitomo Metal in Oita City, Oita Prefecture. The apartment house was completed in November 2015 with the results of the verification obtained from the trial housing incorporated into the design and the construction method.

8.1 Study plan

The study plan was to extract the differences when a three-story building plan was used for a four-story building and to develop a four-story building plan that was as close to the three-story building plan as possible. Examples of the study results are shown below.

8.1.1 Study on external wall specification

In the basic structure of the four-story residential building, the wall structure (section) of the 3rd and 4th floors is different from those of the 1st and 2nd floors and a step is produced on the external wall. To eliminate the step, the thickness of the upper floor wall has to be the same as that of the floors below. In the earlier plan, this step was adjusted by changing the thickness of the outer frame of the ventilation section. However, the results of the verification obtained from the trial housing revealed that the construction labor cost was 1.5 times larger than that of the conventional cost. Therefore, it was decided to eliminate the step by adjusting the thickness of the insulating material. With this, although the material cost increased, construction labor could be greatly reduced and a reduction in cost became possible.

8.1.2 Balcony structure

Through the construction of the trial housing, the structure and the function were verified and the results were fed back to the actual design. In the actual design, although the earlier design employed the load-bearing wall structure for the balcony front wall to secure sufficient load-bearing walls, underground beams have to be built under the load-bearing walls, and this was the major factor in the cost increase when compared with the three-story residential building. As countermeasures, the design was changed in the following manner. By securing sufficient load-bearing walls by employing the double wall type load-bearing walls in the living rooms, and chang-

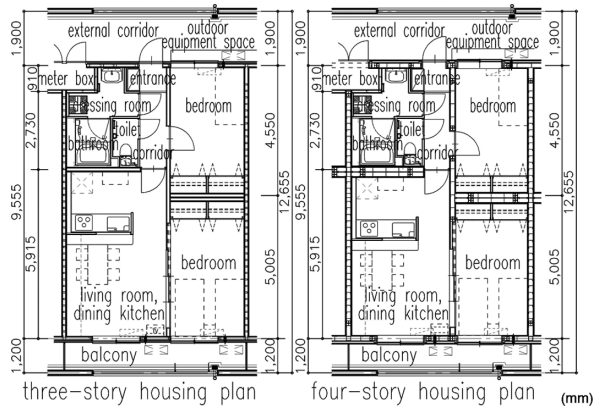


Fig. 8 Third-story and four-story living room plan

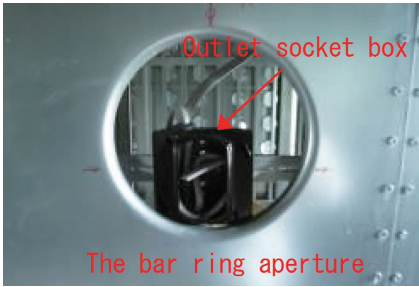


Photo 10 Outlet socket box placement to the bar ring aperture

ing the balcony front end wall from load-bearing walls to supporting walls, the ground beams were made smaller. With this, the same living room plan as that of the three-story residential building became possible (Fig. 8) and the universality of the plan was secured.

8.2 Study on equipment plan and evaluation of construction

In the load-bearing wall of the four-story residential building, different from the conventional surface member material, a load-bearing wall with a surface member material of 1 mm-thick galvanized steel sheet with bar ring apertures opened is used. In determining the diameters and the positions of the bar ring apertures, as the position of the aperture for the equipment is important, the installation positions of the ventilation duct, water supply and drainage pipes and the installation position of the socket box were standardized, the results of which were incorporated into the actual design.

Different from the structural panel with the steel sheet surface member material with bar ring apertures on the 1st and 2nd floors (lower stories), the structural panels on the 3rd and 4th floors (upper stories) are the conventional types. Therefore, a detailed study on the layout of the equipment became necessary to ensure that the positions of the wiring equipment do not differ from each other. The basic standard equipment layout diagram was confirmed in the four-story trial housing, and incorporated into the actual residential building. Since the on-site bar ring aperture opening is difficult, an efficient in-house wiring route should be investigated (Photo 10).

8.3 Construction

8.3.1 Panel diagram

In the load-bearing walls on the 1st and 2nd floors, the steel sheet with bar ring apertures opened is used on one side. Consistency in the integration of the layout of the steel sheet with bar ring apertures in the load-bearing wall layout (outside or inside), the method for joining panels at the T-joint section, and the interaction with



Photo 11 Box form hardware made by cast steel



Photo 13 Improvement tool



Photo 12 Fixed by the sleeve



Photo 14 Improvement wrench socket

equipment need to be checked and the results are to be incorporated into the panel diagram.

8.3.2 Efforts for improvement in shipping of panel

For the jointing mechanism that joins the upper floor load-bearing wall and the lower floor load-bearing wall, the cast steel box form hardware with an enlarged compression-resisting cross section for exclusive use in a four-story residential building (10 kg/piece)³⁾ is used to transfer the axial load. As the hardware itself is heavy, it was fitted to the inside of the panel before shipment to reduce the on-site labor, and safe and smooth progress of construction was enabled (Photo 11).

8.3.3 On-site lifting equipment

The weight of a factory-produced panel of a load-bearing wall with steel sheet material having bar ring apertures is about 1.0 ton (no on-site covering work of steel sheet with bar ring apertures). The weight of each panel is about 25–40% larger than that of the “three-story residential building.” Construction was possible with a 25-t rafter crane. However, depending on the working area radius, the rafter crane was changed to a 50–60-ton type.

8.3.4 Efforts for improving AB accuracy

The installation of AB is conducted using the same construction flow as that of the three-story residential building. However, to date, the lower part of AB has been fixed to the angle steel that runs across the AF at its lower part (an AF structural member) with the U-ring, in the four-story residential building, and AB was fixed by the sleeve to suppress the displacement (Photo 12). As the fixing method with the use of an anchor plate was adopted and the overlapping length of AB in the U-ring method could not be provided, it was decided to use the sleeve. The fixing method with the anchor plate was adopted because the diameter of AB (large hold-down AB in particular) becomes larger than that of the “three-story residential building.” As the overall length increases, the fixing method was used to meet the needs of lowering the material cost and improving the construction efficiency.

8.3.5 Final fastening

As the diameter of AB (hold-down anchor bolt in particular) is larger than that of the “three-story residential building,” the final fastening was performed with the improved tool (Photo 13). In the case of a torque wrench being used, an improved socket is installed at the tip of the torque wrench. Then, the quality control was executed (Photo 14).

9. Future Efforts

Since the start of development in 2006 to the present day, there have been about 30 actual cases of design and construction, and various devices and improvements have been made to the NSSF Construction Method. To develop the method further, we will investigate the subject of “standardization,” which is very effective to enhance the quality and shorten the construction term, jointly and continually with the design (industrial design, structure), equipment and construction sections.

The main subjects to be investigated are:

- (1) Standardization of study plan and wall layout plan
- (2) Standardization of panel manufacturing process
- (3) Unitization and labor reduction in construction

The above subjects are important from the viewpoint of making the most of the NSSF Construction Method, which is characterized by factory production, and by continually striving for improvements, enhanced quality and shorter construction term are expected.

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