New Construction Materials for Social Infrastructures

Hisatoshi Shimaoka*, Kazumi Sawamura** and Takashi Okamoto***

* General Manager, Technology Development, Building & Construction, Department, Building and Construction Center
** General Manager, Housing Products & Materials Department
*** General Manager, Dr., Civil & Building Research Department, Applied Technology Research Center

As a pioneer in construction material technologies, NKK has been continually introducing revolutionary new products to the market, in response to social needs. This paper describes typical products developed by NKK. These products reflect construction material trends, the need for social infrastructures, as well as NKK's approach to developing major technologies and products to meet such trends and needs.

1. Introduction

When production of cold-rolled steel sheets began at the Mizue Steelworks Cold Rolling Mill in the late 1950's, NKK started development of its first construction materials in order to find applications for cold-rolled steel sheets. During that period, NKK introduced the market to various light gauge steel products such as: guardrails, steel decks, and corrugated steel pipes, the production of which was taken over by Nippon Kokan Light Steel Co., Ltd. in the late 1960's. At the same time, NKK also began developing heavy gauge steel products such as steel pipe piles, steel sheet piles, and H-section steel. These became the prototypes of today's major construction products. NKK was the first company to develop most of these construction products. It is for this reason that NKK has been called a pioneer in construction materials.

Following on from its predecessors, NKK has been developing new construction products to meet social needs. The following is a summary of NKK's approach to developing construction products for civil engineering and building structurs.

2. Developing construction products for civil engineering

Responding to the needs of the times, NKK has been producing construction products for civil engineering with a particular emphasis on the foundation piles needed to support the social infrastructures. When developing and commercializing construction products for civil engineering projects, it is necessary for NKK to cope with changing trends in public works, private investment, and technology. The following are some of the ways in which NKK has achieved this. As a countermeasure to the settling in soft ground NKK has developed NF piles covered with a double-layer coating thus reducing negative skin friction. In order to improve the aseismicity of cast-in-place concrete pile, NKK integrated a recently developed steel pipe with a continuous inner spiral rib into a cast-in-place concrete pile, which is named NKTB. So as to increase the bearing capacity steel pipe pile, NKK combined a soil cement column with a steel pipe with an outer continuous spiral rib, which is named HYSC. With Nejiru piles, NKK introduced a manually operated thread joint to replace on-site welding. In the case of the Tsubasa piles, NKK achieved solutions to environmental problems well in advance of all other companies.

This paper describes the NF, NKTB, HYSC, NKK Nejiru, and Tsubasa piles, all of which are typical foundation pile products developed by NKK. It also reports on the present situation in terms of developing large-diameter Tsubasa piles.

3. Typical civil engineering construction products developed by NKK

3.1 NF pile (an end-bearing pile capable of reducing negative skin friction)[1)]

During the 1970's, long steel pipes capable of reaching supporting layers through soft ground were widely used, particularly in waterfront reclaimed sites. As the ground settles, negative skin friction acting on piles constructed on the soft ground causes the piles to settle or the pile materials to depress causing breakage or buckling. This differential settlement can have a harmful effect on the upper structure of the piles. The NF pile was developed to reduce the negative skin friction acting on end-bearing piles and to improve workability.

The NF pile has a double-layer coating on its surface (see **Fig.1**). Inner layer is a sliding one of special-formula asphalt designed to reduce negative skin friction; outer-layer is a protective layer of polyethylene plastic that improves workability. Starting with laboratory tests such as loading tests on model piles, creep tests of visco-plastic materials, impact tests on plastics, and weathering tests, and finishing with site tests such as driving, axial tensile loading, and long-term observation tests, NKK conducted a variety of tests on prototype piles until they finally succeeded in producing a commercially viable NF pile. These piles have been used in construction works on Ohgishima Island and for many other works on waterfront reclaimed sites.

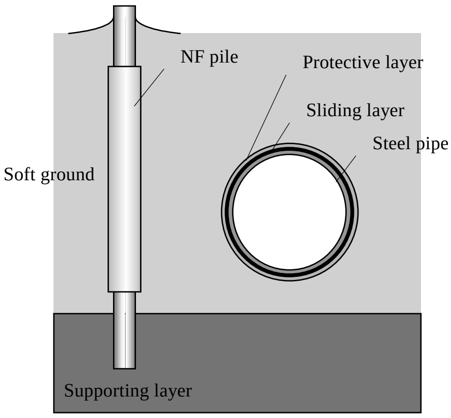


Fig.1 NF pile

3.2 NKTB pile (a cast-in-place pile with an outer steel shell)[2)]

Cast-in-place concrete piles were widely used in Japan when the Miyagi Prefecture Offshore Earthquake occurred in 1978, damaged building foundation piles called attention to the aseismicity of structural foundations. This event aroused fears about cast-in-place concrete piles' resistance to strong earthquake motion. NKK therefore developed the NKTB pile. The NKTB pile is a cast-in-place concrete pile with an outer steel shell. Its pile head, on which large bending moments and shearing forces act, is covered with a continuous spiral-rib steel pipe. NKK developed a new steel pipe with a continuous spiral-rib on its inner surface in order to strengthen the integrated part of the steel pipe with concrete. NKK have also been developing new construction methods such as the simultaneous construction method (see **Photo 1**) that constructs steel pipes and arranges rebars into excavated holes simultaneously. The Hyogo-Ken-Nanbu, Kobe, Earthquake occurred in 1995. It caused no damage to buildings constructed on foundation piles using NKTB piles, proving the aseismicity of these piles. NKTB piles' strong ductility not only results in excellent aseismicity but also enables their diameter to be smaller than those of cast-in-place concrete piles. Using NKTB piles can reduce the production of surplus soil and industrial waste. NKTB piles are acknowledged to be environmentally friendly construction materials. In the field of civil engineering, the NKTB pile was awarded the Public Works Research Center's technical approval in 2000. These will likely be used where ground liquefaction and lateral flow due to liquefaction are expected to occur.

Photo 1 NKTB pile

3.3 HYSC pile (a hybrid steel pipe pile incorporating soil cement)[3)]

The pile-driving method using steel pipes has been widely used for constructing the foundations of civil engineering structures such as bridges. In the method, bearing capacities are estimated by monitoring set per blow, we can secure stable pile installation on supporting layer. Using this method increases the bearing capacity per pile, resulting in increased construction speeds and cost efficiency. The construction method is, however, difficult in city areas due to noise and vibration generated by construction works. In city areas, cast-in-place piles method and pile installation method by inner excavation are more likely to be adopted than the pile driving method. However, these methods cannot supply sufficient bearing capacity. In order to cope with this situation, NKK developed the HYSC pile as a new low-noise, low-vibration method that utilizes the proof stresses of piles effectively.

As shown in **Fig.2**, first a soil cement column is built in order to improve the quality of the soft intermediate ground. During the soil cement in slarry state, a steel pipe with outer continuous spiral ribs or a steel pipe with continuous spiral ribs on its inner and outer surfaces is inserted into the soil cement column (see **Photo 2**). The resultant composite pile consisting of the soil cement column and steel pipe, is known as the HYSC pile. The HYSC pile method generates less noises and vibrations, and does not loosen the surrounding ground or the end ground. The excellent adhesion of the ribs to the soil cement produces a strong bearing capacity with an effective diameter equal to the diameter of the soil cement column. The volume of soil removed by an HYSC pile is about 1/6 to 1/8 of that produced by a cast-in-place concrete pile with the same bearing capacity. The method is effective as a countermeasure to environmental problems.

The HYSC pile obtained the technical approval of the Japan Institute of Construction Engineering, and was described as the new steel-pipe soil-cement pile in the road and bridge specifications revised in April, 2002. Its application to the foundation piles of bridges as well as to other structures is expected in the future.

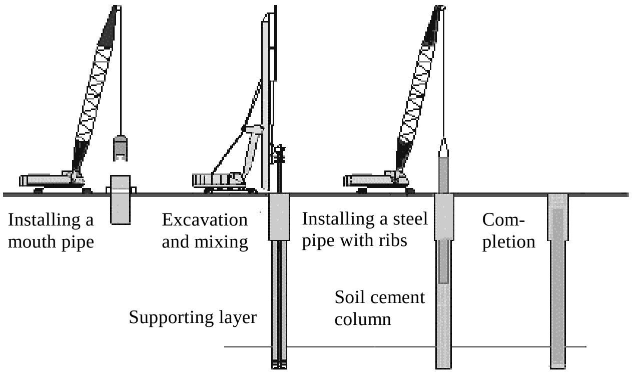


Fig.2 HYSC pile construction method

Photo 2 Steel pipes with ribs

3.4 NKK Nejiru pile (a steel pipe pile with thread joints developed for stopping landslide movement)[4)]

Japanese steep landforms, various ground conditions, and weather conditions often cause landslides. These are the result of shear failure along the moving mass of soil. The number of slide-prevention areas in the whole country reached 20,883 in 1997. In these areas, permanent landslide observations are carried out, and countermeasures such as restraint or control works are undertaken. The total number of these work areas reaches several thousand every year.

Steel pipe piles for stopping landslide movement are inserted into the stable soil under sliding surfaces and fixed. The NKK Nejiru pile method is a typical construction method using restraint works to directly resist landslide forces. Nowadays, in order to reduce construction costs, constructors tend to use thick steel pipe piles with small diameters. In narrow construction spaces, in mountainous areas, constructors are forced to use short steel pipe piles for welding on-site. On-site connection works takes a lot of time. Construction in heavy rain and/or windy conditions can be impossible due to difficulty in job management. Because of these problems, it has been necessary to develop connection technology with particular attention to rationalization and labor-saving at construction sites.

As shown in **Photo 3**, the NKK Nejiru pile has factory-welded screw joints. **Photo 4** shows them being set on-site. The main portion of the steel pipe needs to be thick for design reasons. A seamless steel pipe is used for

Photo 3 NKK Nejiru pile with a screw

Photo 4 Construction scene showing the jointing of NKK Nejiru piles

small-diameter piles, and an UOE welded steel pipe or apress-form steel pipe for those needed to have large diameters. Steel with a tensile strength higher than that of the main portion of the steel pipe is used for screw joints. These are designed to taper so that their thin plates have proof stresses stronger than that of the main portion of the pile. The NKK Nejiru pile embodies a remarkable technology that introduced unwelded joints to steel pipe piles. This technology is highly valued as it greatly contributes to labor-saving in the field of construction.

3.5 Tsubasa pile (a new screw steel-pipe pile with toe wing)

Precast concrete piles have been used for low- and medium-rise buildings in pile installation by inner excavation. Cast-in-place reinforced concrete piles have been used in high-rise buildings. Social requirements are increasing, however, not only in terms of reducing the noise and vibration generated by construction sites in city areas but also decreasing environmental loads such as surplus soil. There is a need to reduce the use of cement milk when considering the possibility of groundwater contamination.

To cope with these requirements, NKK developed the Tsubasa pile method enabling the pile to screw into the ground without removal of surplus soil[5], which was achieved by utilizing the large torsional stiffness of steel pipes. As shown in **Fig.3**, the Tsubasa pile consists of a steel pipe pile and a toe wing made of two semicircular steel disc plates crossed over each other. The toe wing is closed tightly around the bottom of the pile, facilitating the pile's screwing into the ground and providing a large end-bearing capacity. The Tsubasa pile is an ideal foundation pile since it has the capability to reduce costs by virtue of its large end-bearing capacity and facilitate construction without removing soil, and also act as countermeasures to environmental problems. In February 1999, as a first step, NKK has commercialized and begun to sell Tsubasa piles with different diameters from 318.5 to 508mm (wing diameters are twice the respective pile diameters). As a second step, NKK has tried to improve the Tsubasa pile's aseismicity, and developed an enlarged pile-top type with a significantly increased lateral-bearing capacity. As shown in **Fig.4**, NKK enlarged the pile-top of the conventional Tsubasa pile in order that the pile can be joined to a general steel pipe through a disc joint. After conducting construction tests, on-site lateral loading tests, and FEM (Finite Element Method) stress analyses, NKK determined the combination of shapes and dimensions (see **Table 1**). The Tsubasa pile method uses a general-purpose motor installed on a three-point supported pile driving machine in order to give torque to the steel pipe pile from its pile-top (see **Fig.5**). This enables the pile to screw into the supporting layer and embed itself. **Photo 5** illustrates the Tsubasa pile at a construction site.

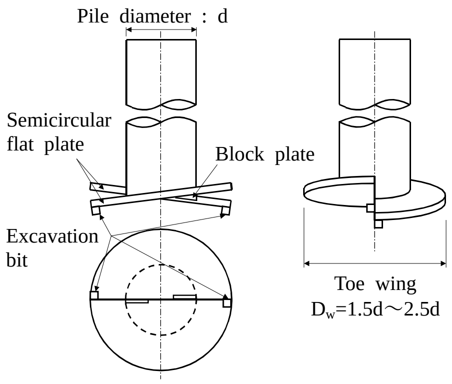


Fig.3 Tsubasa pile composition

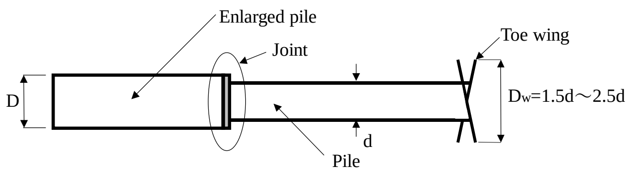


Fig.4 Tsubasa pile (enlarged pile-top type)

Table 1 Combination of pipe's outer diameters and enlarged pile-top diameters

Pipe's outer diameter (mm)	Enlarged pile-top diameter (mm)					
	400, 406.4	450, 457.2	500, 508.0	600	700	800
318.5	○	○	○			
355.6	○	○	○			
400, 406.4		○	○	○		
450, 457.2			○	○	○	
500, 508.0				○	○	○

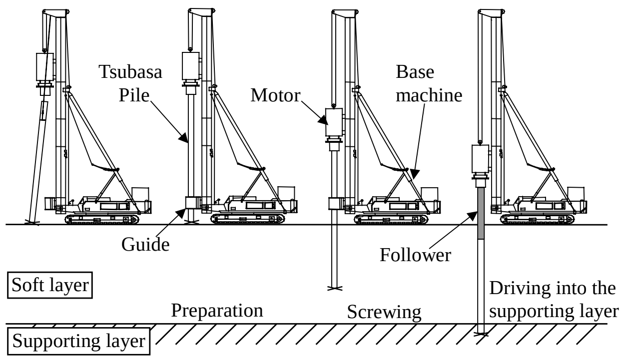


Fig.5 Tsubasa pile construction method

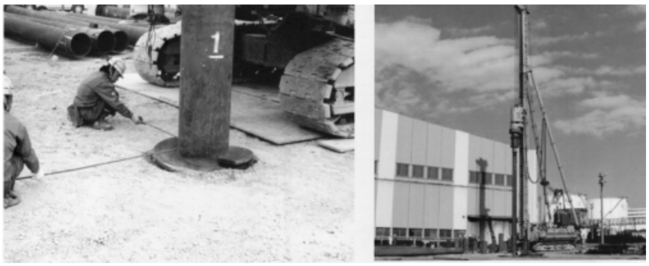


Photo 5 Tsubasa pile in use at a construction site

The regular-type Tsubasa pile (diameters 318.5 to 508mm) obtained Building Center of Japan technical approval in December, 1998; the enlarged pile-top type in May, 2000. Since being awarded the Public Works Research Center's technical approval in May, 2001, these piles can be widely applied as foundations in civil engineering projects and building structures.

As the next step, NKK is developing Tsubasa piles with larger diameters (hereafter called 'large-diameter Tsubasa piles') that are intended for high-rise buildings. These will be competitively priced compared to those constructed from cast-in-place concrete piles[6].

The large-diameter Tsubasa pile has a similar shape to the conventional Tsubasa pile. Its diameter ranges from 600 to 1200mm; its wing-diameter to pile-diameter ratio from 1.5 to 2.0 (see **Table 2**). Its ultimate vertical bearing capacity is expected to be in the range 10000 to 40000kN. NKK is also trying to increase the lateral bearing capacity of the enlarged pile-top type, setting the target ratio of the enlarged pile-top-diameter to pile-diameter ratio at 1.5.

Table 2 Relationship between pile and wing diameters

Pipe's outer diameter (mm)	Ratio of toe-wing diameter to pile diameter	Toe wing	
		Diameter (mm)	Thickness (mm)
φ 600	1.5 1.75 2.0	900～1500	20～35
φ 700		1050～1400	20～45
φ 800		1200～1600	20～50
φ 900		1350～1800	20～55
φ 1000		1500～2000	20～60
φ 1100		1650～2200	20～65
φ 1200		1800～2400	20～70

Compared to the conventional Tsubasa pile, the large-diameter Tsubasa pile needs a large torque to penetrate the ground. NKK therefore uses a strong rotary machine which grabs pile body and rotate it continuously (see **Fig.6**). **Photo 6** shows the pile in use at a construction site.

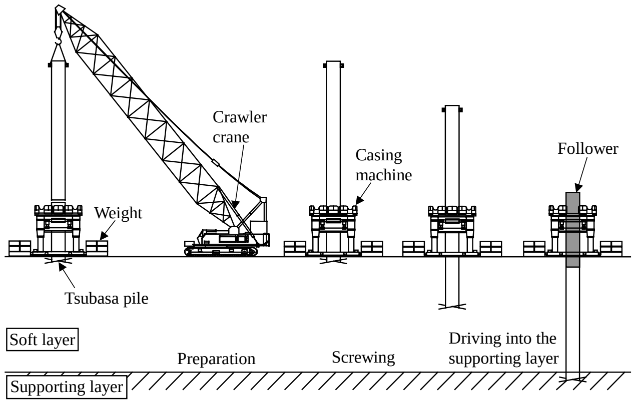


Fig.6 Construction method of the large-diameter Tsubasa pile using a casing machine

Photo 6 Large-diameter Tsubasa pile in use at a construction site

Fig.7 shows one example of the various construction test results on the rotary casing jack method. Setting pile diameter at 1200mm, wing diameter at 2400mm, wing inclination at 14.4°, penetration depth into the supporting layer at 1200mm, 1.0×d. NKK constructed a test pile. The construction ground has an intermediate sand layer with an N-value greater than 50 at G.L.-47 to G.L.-50m. The supporting sand layer starts at G.L.-58.6m.

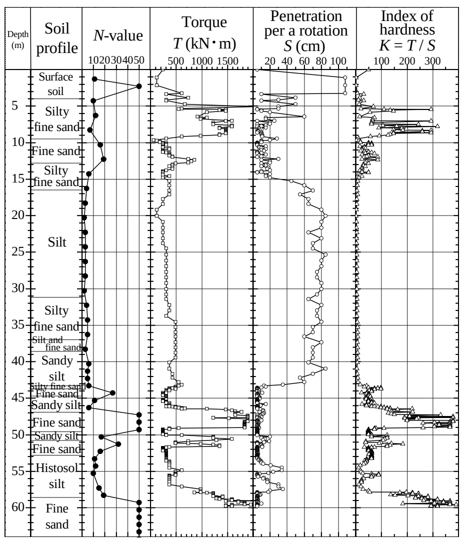


Fig.7 Test result example (d=1200m)

In terms of construction quality control, identification of the supporting layer and the reliable penetration of the pile are extremely important factors. When making rotary penetration, the hardness index K (kN･m/cm) expressed by Equation (1) defined as torque T divided by penetration depth S per rotation is used to judge the arrival of the pile at the supporting layer.

$$K=T/S \qquad \cdots\cdots(1)$$

The construction test results (see **Fig.7**) demonstrate that the hardness index K clearly changes in the vicinity of the supporting layer corresponding to the change of the N-value, indicating the penetration of the pile into the supporting layer.

After these construction tests, NKK performed real-size static load tests on large-diameter Tsubasa piles with pile diameters of 800 and 1200mm. Putting strain gauges on six cross-sections in terms of the direction of depth, NKK measured skin friction and pile-top bearing capacities for each layer. The static load tests were conducted in conformity with The Japanese Geotechnical Society standards. **Photo 7** shows the static load testing site. The maximum pile-top loads for d=800mm and d=1200mm were 21500kN and 44100kN, respectively. According to the load transfered from pile-top to pile-toe, the load-displacement curve normalized by respective wing areas and wing diameters was obtained, proving that the pile-toe bearing capacities were approximately proportional to the wing areas. Based on these results, it was concluded that the enlarged diameters gave little effect to the pile-toe unit bearing capacities and hence could be evaluated by using the bearing capacity formula for the conventional Tsubasa pile.

The large-diameter Tsubasa pile, as well as the enlarged pile-top type, obtained the approval of the Minister of Land, Infrastructure and Transport in June, 2002. NKK expects that this pile will acquire the Public Works Research Center's technical approval in the near future.

Photo 7 Static load test (d=1200mm) site

4. Developing construction products for building structures

Properties such as strength, toughness, and weldability are required for steel materials intended as the structural elements of steel-framed buildings. Responding to the trend of improving structural material strength, NKK has been analyzing the damage caused by major earthquakes and carrying out the necessary experiments, analyses, and studies to supply steel materials that are both cost efficient and sufficiently effective to the market. One of the major targets in the building construction industry is the reduction of construction costs through the rationalization of members and the simplification of construction. In order to reach this target, NKK has not only been supplying steel materials to customers but also proposing semi-assembled members, as well as construction methods to the market. In the field of housing materials, NKK has also been researching and developing ways of utilizing the advantages of steel materials.

NKK's typical structural steel products intended for buildings, semi-assembled steel members including their construction methods, and housing materials, are described below, along with the company's approach to their development.

5. Structural steel for buildings

5.1 SA440

Table 3 shows the latest structural-steel products for buildings developed by NKK. These were developed to meet the most recent seismic design methods that focus on the plastic deformation capacity. The material alerted NKK to the plastic deformation capacity was a so-called low-yield ratio 60kgf/mm^2-class steel. The yield point of conventional structural steel was set at a value 20% lower than its tensile strength to ensure it retained its plastic deformation capacity after yield. Conventional steel manufacturing technology, however, could not produce

Table 3 Latest development in steel for building structures

Steel type	Application range
SN400, 490	Thick plate, section steel
STKN400, 490	Circular hollow section
HIBUIL325, 355, 385	Thick plate
SA440, NKK-SA440-U	Thick plate
BCR295	Roll-formed steel square tube
BCP235, 325	Press- formed steel square tube
NKBCP440	Press- formed steel square tube
HIBUIL-H325, 355, 440	TMCP ultra-heavy H-section
NK-LY100, 160, 225	Ultra-low-yield strength steel

low-yield ratio steel with high strength as well as a large plastic deformation capacity, consequently, such steel has been rarely used in buildings. Combining a leading-edge structural design method technology with the latest manufacturing technology, NKK has succeeded in commercializing this product for the first time in Japan.

The steel was first used in the Kowa Kawasaki Higashiguchi Building (see **Photo 8**). Prior to its application in this building, NKK carried out experiments on full size beam-to-column connection in order to prove its safety in earthquakes (see **Photo 9**). The 60kgf/mm^2-class thick steel plate (590N/mm^2-class steel) then became a subject of a comprehensive development project by the Ministry of Land, Infrastructure and Transportation under the guidance of government, academia, and the private sector. Its specifications were standardized as SA440, the common industrial standard. As a pioneer in the low yield-ratio 60kgt/mm^2-class steel, NKK received the Minister's approval for the circular hollow section (NT-SA440), the ultra-heavy H-section (HIBUIL-H440), and the cold-formed square hollow section (NK-BCP440) in advance of all other companies, and established its position as a leader in the field of steel used for columns.

Photo 8 Kowa Kawasaki Higashiguchi Building

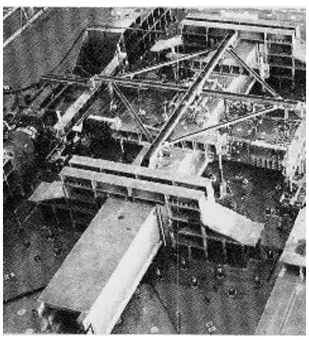


Photo 9 Full size beam-to-column joint test

5.2 HIBUIL385

In April 2002, HIBUIL385 became the most recent structural steel for buildings produced by NKK to obtain material approval from the Minister of Land, Infrastructure and Transport.

The increasing height of high-rise buildings and the adoption of mega-structures have led to the need for increasing thickness in steel used in buildings. Improving weldability of thick plates, NKK has controlled the composition of steel by lowering the carbon equivalent and weld-cracking parameters (Pcm). Using a thermo-mechanical control process, the newly developed steel does not need to reduce specified design strength (F-value), even in the case of a plate thickness greater than 40mm. As shown in **Fig.8**, NKK has developed three types of steel with F-values of 325, 355, and 440N/mm^2. When considering the large differences in strength and price between the 355N/mm^2- and 440N/mm^2-class steels, NKK also developed the 385N/mm^2-class steel in order to offer customers a wider selection.

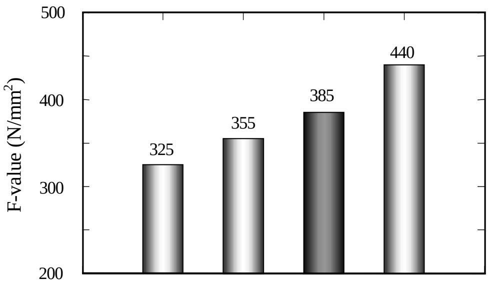


Fig.8 Comparing HB385 to conventional steel

Table 4 shows the product grades and applications of HIBUIL385. **Table 5** shows the mechanical properties of HIBUIL385. The average area reduction of HIBUIL385C OL in terms of plate thickness is specified as being equal to or larger than 25%. The minimum area reduction is equal to or larger than 15%. Both HIBUIL385B OL and HIBUIL385C OL guarantee Charpy-absorbed energy equal to or larger than 70J at 0°C.

Table 4 Plate thickness of HB385

Grade	Thickness
HIBUIL385B OL	19mm≦ t ≦100mm
HIBUIL385C OL	

Table 5 Mechanical properties of HB385

Grade	YP/YS (N/mm^2)	TS (N/mm^2)	YR (%)
HIBUIL385B OL	385≦ ≦505	550≦ ≦670	≦80
HIBUIL385C OL			

In order to verify the structural performance of steel when used as structural members in buildings, NKK conducted the following tests: (1) stub-column tests on a built-up box section as well as a built-up H-section; (2) a cyclic loading test on a beam-to-column connection using a T-section test specimen, and (3) a cyclic bending test on a built-up box-section column. The following is a summary of the cyclic bending test on a built-up box-section column.

As shown in **Fig.9**, a cyclic load was imposed on the built-up box-section column at the center, a distance of 5m between the supporting points. The cross-section of the test specimen was □-500×19mm (width-thickness ratio 26.3) assembled by submerged arc welding (welding material: KW55X, KB55I). An inner diaphragm (32mm thick) was electroslag-welded to the loading portion.

Table 6 shows the measured dimensions of the test specimen and its properties obtained from material test results. Using as the reference the deflection δ_p at the center portion of the span corresponding to the full plastic moment of the specimen, a cyclic deflection of 2 δ_p, 4 δ_p, and 6 δ_p were applied, twice respectively, then finally, a deformation of up to 10 δ_p, was applied to the specimen.

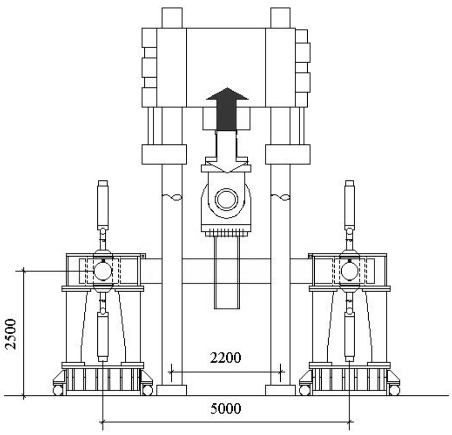


Fig.9 Bending test set-up

Table 6 Sectional properties of the specimen

	Z_y (cm^3)	Z_p (cm^3)	δ_y (mm)	δ_p (mm)
□-501×19.9	5919	6913	15.4	18.0

Fig.10 shows the relation between the bending moment and the slope angle of the test specimen. **Photo 10** shows the loading portion after testing. Local buckling of the column flange occurred at the cyclic deflection of 6 δ_p, however reduction in proof load was small, indicating that the hysteresis characteristics of the specimen were stable.

This type of H-section steel has technical approval for use as a building material. Applications for the circular hollow and cold-formed square hollow sections are currently intended to meet the various types of structures.

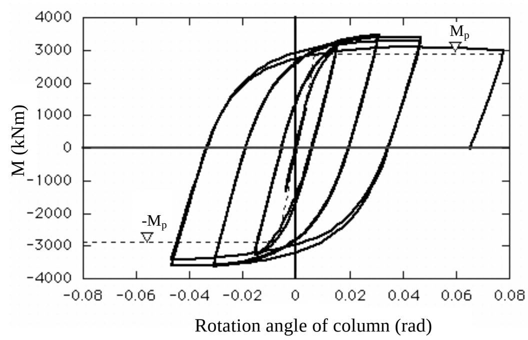


Fig.10 M－θ relationship

Photo 10 Loading portion of the specimen after loading

6. Semi-assembled steel members and their construction methods

6.1 NT column

The NT column (see **Photo 11**) is a circular hollow-section column with connection members of the through column type, to which outer ring stiffeners are integrated by welding. In order to construct an original design formula applicable to special cases where the beams are eccentric and the rings are cut at the joints to the beams, the flexibility of the design was increased.

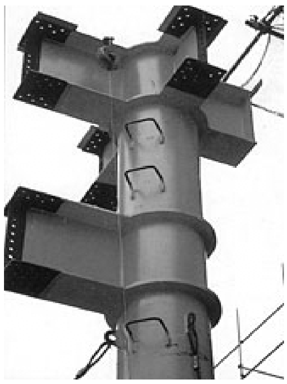


Photo 11 NT column

6.2 Hysteretic damper

Seismic dampers with low-yield strength steel are often used in high-rise buildings. NKK has developed three types of hysteresis damper (see **Fig.11**) as well as steel with a unique strength level (LY160). These devices are now being supplied to customers. **Photo 12** shows an applied example of Type A.

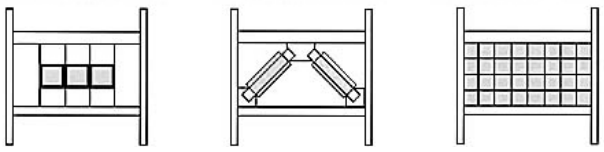


Fig.11 Hysteretic dampers

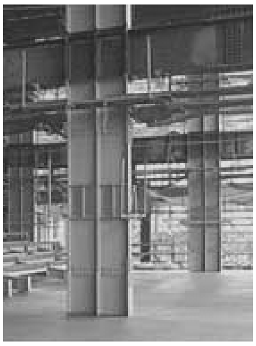


Photo 12 Hysteretic damper (Type A)

6.3 CFT

NKK has studied the structural characteristics and fire resistance efficiency of concrete-filled tubes, which are widely used in columns bearing high-axial forces as well as other applications. To this end the company has developed placing technology including the mixing of concrete. NKK has also established a construction method of filling the tubes having inner-projection of diaphragms with concrete. Construction tests on the tubes (see **Photo 13**), were carried out thus proving this method.

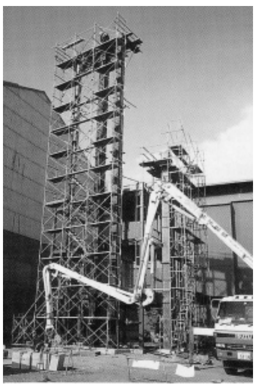


Photo 13 Construction tests on the CFT

The Ichi-ichi method of embedding the column bases of upper structures in the pile-top portions of cast-in-place concrete-filled steel pipe piles is based on a well-known connection mechanism between piles and columns. This provides for highly reliable column-to-pile joints. **Photo 14** shows the column-to pile joint used in this method. This technique makes it easy to join steel-footing-beams to a steel column directly above a pile-top. It can also enable to eliminate the footing and to decrease footing-beam cross-sections, which contribute to reduce the volume of excavated soil. NKK has developed an evaluation method of the structural performance of the column-to-pile joints, a design method of integrating upper structures with lower ones, and the construction methods needed for columns and piles.

Photo 14 Column-to-pile joint

6.4 Earthquake resisting joint

After the Hyogo-ken-nanbu, Kobe, Earthquake in 1995, many cases of brittle failure in the vicinity of the welded joints between the through-diaphragms of steel-pipe columns and H-section steel beam-flanges, were reported. This experience triggered research on steel materials and welding. The Building Standards Act revised following this earthquake included regulations on the dislocations of through-diaphragms and beam-flanges.

NKK has studied the shape of through-diaphragms in order to prevent brittle failure at beam-ends and improve deformation capacities. These can be achieved by the use of two types of NKK-TAISHIN joints: bolted and welded.

The bolted-joint type combines the through-diaphragm with the flange portion of the bracket, joining the beam by means of high-strength friction bolting [**Figs.12** and **13**(a)]. This type of joint has a wider flange-width that provides the flange with an wider effective cross-sectional area. As a result, the formation of plastic regions starts at the bolted portions near the beams farthest from the column, allowing the H-section beams to make full use of their deformation capacities.

The welded-joint type has projections with rounded inside corners at the joints of the through-diaphragms to the beams. The beams are welded to the flanges on-site [**Fig.13**(b)]. The effect of the rounded portion's shape eases the concentration of stress, preventing the failure of the welded joint.

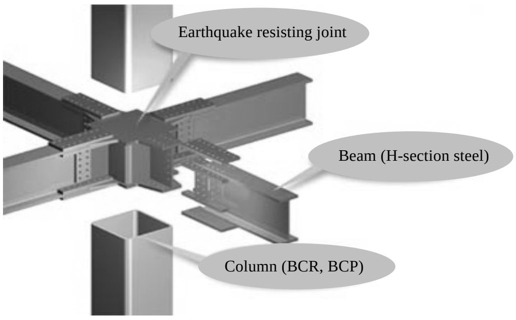
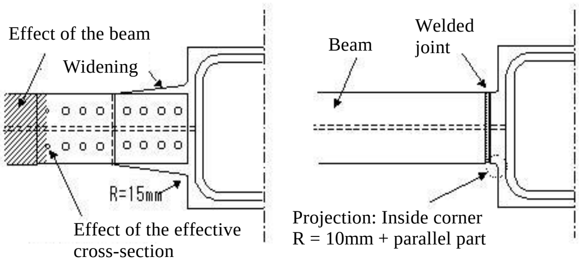


Fig.12 NKK-TAISHIN joint



(a) (b)

Fig.13 NKK-TAISHIN joint details

Cyclic loading tests were performed on the T-shaped specimen (see **Fig.14**) to verify the structural performance of the earthquake resisting joints described above. Having considered that the fracture rates of bolt holes and the yield ratios of beams affect the deformation capacities of the bolted-type joints, experiments were carried out according to these parameters. Setting the beam width as the parameter to be measured, an FEM analysis of the welded-type joint was performed in order to determine the radius of effective curvature needed to ease the stress concentration.

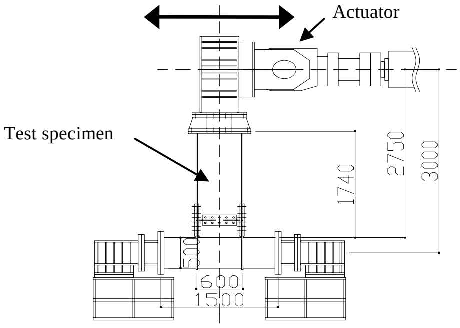


Fig.14 Earthquake resisting joints test set-up

Table 7 shows the mechanical and sectional properties of the specimen resulting from the test results. The parameter Z_{pe} refers to the plastic section modulus with consideration given to fractured bolt holes. Sufficient torque-shear type high-strength bolts (S10T, M24) were used to meet the beam's full plastic moment strength. The materials for the beam and the diaphragm were 400N/mm^2- and 490N/mm^2-class steel, respectively, with the same plate thickness.

Table 7 Mechanical and sectional properties of the specimen

	σ_y (N/mm^2)	σ_u (N/mm^2)	Z_p (cm^3)	Z_{pe} (cm^3)
H-600×200×9×22	270	429	3280	2619

Fig.15 shows the relationship between the bending moment M at the column face and the displacement δ at the loading point. The vertical and horizontal axes are normalized by M_p (the full plastic moment of the beam at the column face) and δ_p (the elastic deformation at the loading point corresponding to M_p), respectively. After showing stable hysteretic loops through to the last two cyclic loadings, the specimen finally started to fail with slow clack at the position of the farthest fractured bolt hole, thus finishing the loading test.

The specimens, including one that was a welded type, demonstrated sufficient deformation capacities in a practical range, proving the effectiveness of the methods using these joint types.

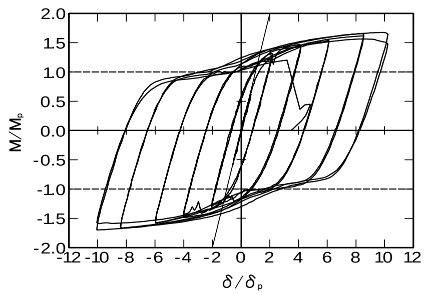


Fig.15 Normalized M－δ relationship

7. Steel for housing

NKK developed two systems using galvanized steel sheets for steel-frame housing: the steel house and the NKK Frame Kit.

7.1 Steel house (a light-gauge steel-framed house)

The light-gauge steel-framed house has a panel-type structure. Galvanized steel sheets approximately 1.00mm thick are formed to channel or box profile, of which outside dimensions are same as those of lumbers used in the wooden two-by-four construction. The steel profiles are then joined together with drilling tapping screws. Finally, structural plywood is fixed to the frame.

In Japan, steel manufacturing companies have been leading in the development of design and construction methods of steel house. The results commonly usable in the industry are published by the Ministry of Land, Infrastructure and Transport as Notice No. 1641.

The major market for steel houses is standardized apartment houses, as a result, NKK is developing original heat insulation structures and bearing walls for these buildings. **Photo 15** shows exterior construction tests of a two-story apartment house.

Photo 15 Appearance of a two-story apartment house used in construction tests

7.2 NKK Frame Kit

The NKK Frame Kit is a set of structural steel, galvanized light steel members, for houses incorporating high durability and aseismicity.

Photo 16 shows the framework of the NKK Frame Kit. It uses structural square steel tubes, 75mm square with a thickness of 3.2 to 4.5mm, for the columns and build-up H-section steel ranging in size from BH-250×99×4.5×4.5 to BH-250×100×6×9 for the beams. It can be adapted for houses up to three stories high.

Photo 16 Framework of the NKK Frame Kit

NKK Frame Kit are built with shear wall of the braced-panels with M20 or M22 turnbuckles. The panel has a proof load approximately 1.7 times that of a standard wooden two-by-four panel of the same width[8], resulting in smaller number of bearing walls, and consequently, enabling designers to plan more flexible layouts.

Using a unique structural calculation program, NKK has established a system of determining the arrangement of structural elements, that simply involves entering the desired layout into the computer. Construction companies unfamiliar with steel structures can thus easily design houses using the NKK Frame Kit. NKK makes detailed structural calculations based on the agreed layout. NKK can also supply columns, beams, and other members cut to standardized sizes together with joint metals and construction manuals. At construction sites, constructors can assemble these materials by bolting them to form the complete framework of the house.

The heat-bridge phenomenon of steel members within steel houses can lead to the development of problems with condensation and heat insulation. The outside insulation method is an effective way of solving these problems. Fixing sidings onto a steel framework is not always easy for construction companies familiar with wooden buildings. To solve the problems of condensation and heat insulation and to make exterior construction work easier, NKK has developed insulator-installed exterior substrates (see **Photo 17**) for the NKK Frame Kit.

Photo 17 Insulation system of the NKK Frame Kit

8. Conclusion

When developing construction products, it is necessary to deal with such requirements as: aseismicity, environmentally friendly materials and methods, labor-saving at construction sites, and further reductions in construction costs. It is important for NKK to listen to the needs of society and the times in which we live, to view the market broadly, to challenge technological breakthroughs, and to strategically and steadily make progress towards the company's goals. Based on NKK's history and technology that NKK has developed, including several leading-edge products and methods, NKK is determined to continue developing ways of meeting society's needs ahead of all other companies.

References

1) Hamamoto et al. "New steel pipe pile that reduces negative friction". Architectural Technology. No.287, pp.121-137(1975).
2) Hirose et al. "Case-in-place steel pipe concrete pile". NKK Giho. No.107, pp.46-54(1985).
3) Yoshida et al. "Hybrid steel pipe pile with soil cement". NKK Giho. No.166, pp.27-32(1996).
4) Takano et al. "Steel pipe pile with thread joints for stopping landslide movement (NKK Nejiru pile)". NKK Giho. No.151, pp.53-56(1995).
5) Okamoto et al. "New screw steel pipe pile with a toe wing (Tsubasa pile)". NKK Giho. No.169, pp.41-46(2000).
6) Hayashi et al. "Large-diameter Tsubasa pile". NKK Giho. No.178, pp.37-42(2002).
7) Ueki et al. "Verification of the deformation capacity increased by the improvement of the details of beam-column joints". Summaries of papers. Convention of the Architectural Institute of Japan, 2002.
8) Itoh et al. "Structural properties of 'NKK Frame Kit'". NKK Giho. No.175, pp.21-25(2001).