Technical Topic

UDC 725 . 4 : 669 . 1

Design and Construction of Factory Architecture in the Dawn of Domestic Steel Structures

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Abstract

The factory buildings of the Imperial Yawata Steel Works, which commenced operation in 1901, were the first full-scale steel architecture by German designers. The first domestic steel architecture designed and built by Japanese engineers originated in 1909, when self-produced steel came into use. The designer of this building was a mechanical engineer who was at that time a young graduate from university. By 1916, with the advance of design techniques and technology, architectural engineers from both Japan and overseas were invited to design factory architecture. As factory construction settled in the 1930s, the visiting architectural engineers retired, leaving the civil engineers to work on factory building design. Architectural engineers were once again responsible for architectural design, like it is today, around 1940. This paper describes the history and architectural details of each era.

1. Introduction

The construction of the Imperial Yawata Steel Works (hereinafter referred to as Yawata), which started operation in 1901, was a major national project and the factory buildings were large steel structures unprecedented in Japan.

In the last days of the Tokugawa Shogunate regime, the architecture prevalent at that time used cast iron and/or wrought iron for roof trusses. However, steel structure architecture in Japan did not emerge until the invention of the Bessemer converter method, which allowed the mass production of steel, in 1856 in Britain. Therefore, the Shueisha completed in 1894 is considered to be the first steel structure building in our country [1].

However, the factory buildings constructed at the start of Yawata's operation were the first in terms of large-scale steel structure architecture [2], indicating that the construction of steel structure buildings started significantly at that time. However, due to the lack of technological capability in our country then, Japan was fully reliant on foreign countries for the entire process from the design, procurement of steel materials, fabrication and erection to the completion of the factory buildings.

Hereafter, based on the example of the Repair Shop that still exists today, I shall shed light on the state of construction in those days and introduce the development process of the steel structure architectural technology, by presenting the outline of Yawata steel structure factory buildings built since then until the early days of Showa, and the construction and design transitions.

2. Organization for Construction

The organization at the time of the construction of Yawata was composed of: the director general, vice-director general in charge of engineering affairs (chief engineer), and below this, was the engineering department in charge of construction. Michitaro Oshima, the vice-director general in charge of engineering affairs, also held the position of general manager of the engineering department. The engineering department was composed of: the civil engineering section (Haruki Obinata), architecture section (Kuniyoshi Kamiya), mechanical engineering section (Yoshiaki Yasunaga) and inspection section. Among these, the first installation subsection of the mechanical engineering section was in charge of the factory building construction [3]. This means that the factory building was considered a part of the machinery equipment. Meanwhile, the civil engineering section took charge of dredging, land-filling, harbor affairs, railroad affairs and so forth, while the architecture section was responsible for the design and construction of office buildings, official residences and so forth.

As the construction of the factory buildings was promoted under the said organization under the guidance of German engineers, for a certain period of time afterwards, the design and construction of fac-

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tory buildings in Yawata was undertaken by mechanical engineers.

3. Factory Buildings at the Time of Start of Operation in Yawata

3.1 Repair Shop

The Repair Shop completed in 1900 (**Photos 1**[4]**–3**) is the only factory building built at the start of operation of Yawata to survive today in its complete form at the same site and is a very valuable asset that was registered as a UNESCO World Heritage site in 2015 together with the former Forging Shop, former First Head Office and the Onga River Water Resource Pumping Station. The Repair Shop is still used by the Yawata Iron and Steel Works to this day.

The shop consists of a main building and a lean-to on either side. The main building measures 15 m wide in span, 11.5 m high in eave height and 140 m long in ridge direction, which was extended from the original 50 m in three developments (**Figs. 1**[5]**–3**[5]).

3.1.1 Designer

The entire process of the construction from the design, steel material fabrication to erection was entrusted to the Gutehoffnungshütte A.G. (hereinafter referred to as G·H·H) in Germany, which is confirmed by the signatures on the drawings that still exist. Furthermore, as the hallmark "GUTEHOFFNUNGSHÜTTTE NO 30" is stamped on the channel steel used for members of the building of the subject shop, this proves that the fabrication and the erection together with the supply of the steel materials were provided by the said company.

3.1.2 Structural form

The roof truss design of all of the factory buildings at the time of Yawata's operation was round-shaped and of the king post truss type. Although the reason for the employment of the design of the round-shaped roof is unknown, it is assumed that the round roof design was one of the common designs at the time because factory buildings with round-shaped roofs are introduced in the company records of G·H·H of that time. However, as the fabrication, transportation and the erection of the members of the round roof design building were troublesome, there are no round-shaped roof designs in the factory buildings of the Yawata Iron and Steel Works built at a later date.

As there is no documentation available regarding structure calculation, details such as loading conditions are unknown, and the roof truss is characterized by the pin-joining of the principal rafter ends with columns, as well as by the large members (channel steel

Photo 1 Repair Shop in May 1900 (second building from right)[4]

Photo 2 Present Repair Shop

Photo 3 Interior of Repair Shop

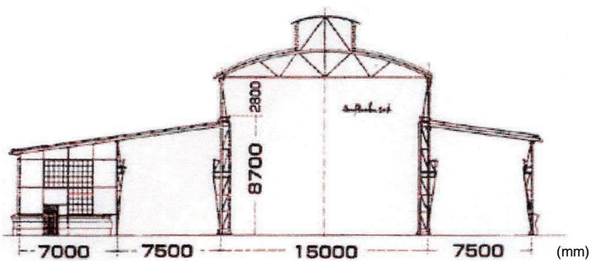

Fig. 1 Section drawing of Repair Shop[5]

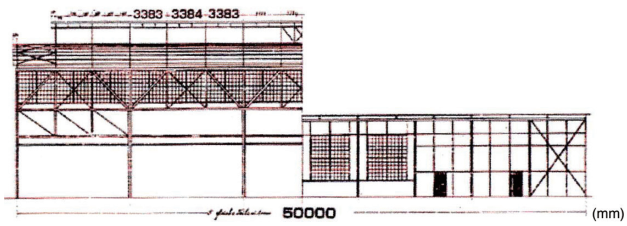

Fig. 2 Framing elevation drawing of Repair Shop[5]

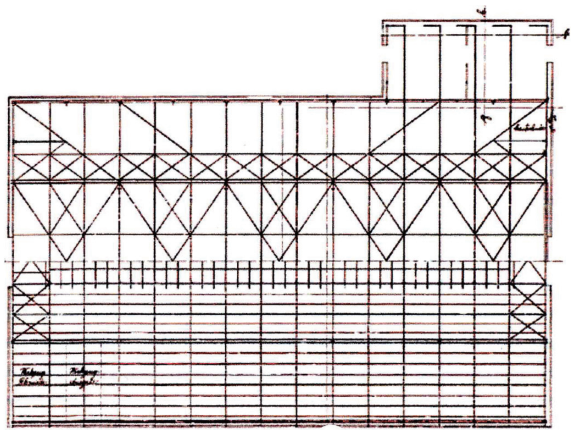

Fig. 3 Roofing framing plan of Repair Shop[5]

250 × 90) built in a diagonally crossing manner used as the horizontal brace on the roof truss face to enhance the rigidity of the roof truss (Fig. 3 [5], Photo 3). This indicates that the structure calculation model was used for the entire structure of the roof as a rigid body and pin-joining was set for the connection with columns.

3.1.3 Specification

As stated in an old budget document that still exists [6], "the estimated cost was 80 Japanese Yen per tsubo (3.3 m^2) on the basis of brick wall, steel column and NAMAKO roofing", the wall is built of red brick with corrugated steel sheets used as the roof material (NAMAKO is considered to be corrugated steel sheets). In addition, a unique rectangular crane rail 60 mm wide and 50 mm high is indicated in one of the drawings. However, the said roof material and the crane rail installed at its early stage were replaced and no longer exist.

3.1.4 Steel material

Metric units are used to indicate the dimensions of the German steel materials on drawings ("NO 30" of the aforementioned hallmark indicates 30cm), and channel steel, angle steel, I-shaped steel and plates are used for the major members. The purlin are tied with round steel bars used as a steady brace to suppress the deflection. To stop the motion of the front edges of the round bars, hat-shaped steels are installed at the eave edge in the direction parallel to the direction of the purlin (**Photo 4** [7]). This design is not found in factory buildings other than those designed by G·H·H for the factory buildings at the start of operation. As for the performance of steel materials, based on the results of the tensile strength test and the steel composition analysis (**Table 1** [8]) of the samples conducted on site, the tensile strength is 362.8–382.5 N/mm^2 and the steel maintains a certain quality level as a common steel.

3.1.5 Foundation

The foundation is an independent type and judging from the existing drawings, pine tree piles 2 KEN (3.6 m) long and 3 KEN (5.4 m) long are used together. A unit of 30–70 piles is used as the foundation. For the foundation material, concrete is used with red brick masonry above it. Anchor bolts are embedded in the red brick part [7]. Furthermore, separate foundations are connected by an arch type bridge of brick masonry, structured to support the brick wall above it (**Fig. 4** [5]). At the time, the ground was at a lower level; the foundation was built on the ground level subsequently followed by the building, and the new ground was formed later by land fill. This type of foundation is the same as that of the adjacent former First Head Office with its brick masonry (stated below) that was designed in our country at the same time (**Fig. 5** [5]).

Furthermore, only the assembly drawings, the outline drawings of the independent foundation and the anchor bolt plan drawings were submitted by G·H·H as the foundation drawings. The detailed design drawings with detailed geometry and dimensions and the drawings of the arch are provided with Japanese descriptions, wherein the dimensions are given in SHAKU units (the traditional Japanese unit of measurement of length, distance, one SHAKU = 303.030 mm). This, together with the case of the foundation of the former First Head Office shows that the implementation of the actual detailed design of the foundation was conducted in Japan.

3.2 Former Forging Shop

The former Forging Shop that was completed in 1900 measured 15 m wide in span, 11.5 m high in eave height and 25 m long in ridge direction at the time. In 1909, it was extended by 30 m to 55 m. The shop was relocated to another location in 1917 and is currently used as the document storage office of Yawata Iron and Steel Works. The designers, structure type, specification and the steel materials are the same as those of the Repair Shop (**Fig. 6** [5], **Photo 5**). Furthermore, the existing G·H·H design drawings are titled Hammerschmiede für das Kaiserliche Stahlwerk Japan, which gives an indication of the pride felt at that time for the national project.

3.3 Former First Head Office

This is the former First Head Office at the time of the start of operation considered to have been completed in December, 1899. It measures 15.57 m wide on the gable face, 32.7 m long in ridge direction and 10.4 m high in eave height. It is a two-story building of red brick masonry with a total floor space of 1 023 m^2 (**Figs. 7** [5], **8** [5],

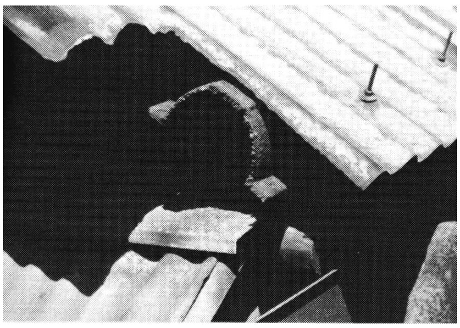

Photo 4 Hat-shaped steel [7]

Table 1 Compositions of steel (channel steel) [8]

(%)

C	Si	Mn	P	S	Cu	Ni	Cr
0.04	0.01	0.133	0.025	0.025	0.04	0.03	0.01

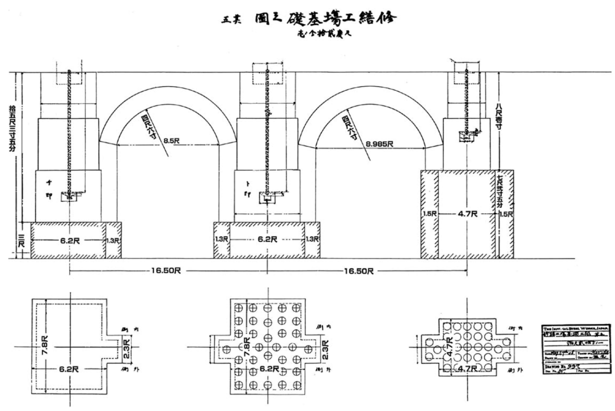

Fig. 4 Foundation drawing of Repair Shop [5]

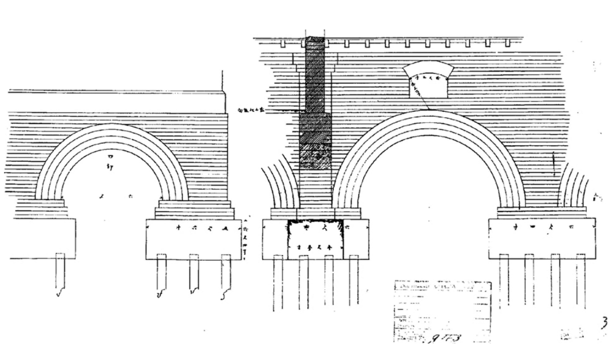

Fig. 5 Foundation drawing of former Main Office [5]

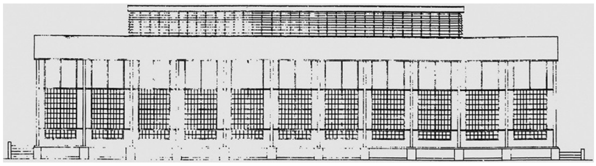

Fig. 6 Elevation drawing of Former Forging Shop [5]

Photo 5 Former Forging Shop

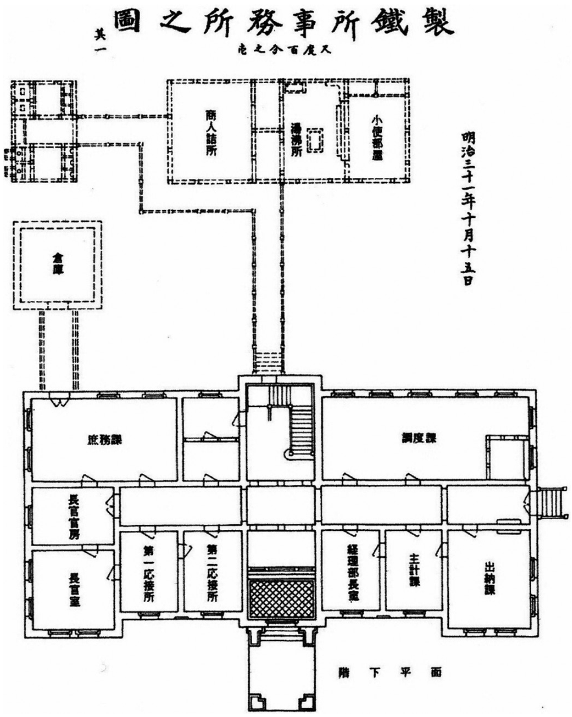

Fig. 7 First floor plan of First Head Office [5]

Photo 6).

3.3.1 Designer

Although the identity of the designer of such structures is unknown, the following descriptions are found in the document dated March 19th, 1897 (the 30th year of Meiji): “As per the provision specified for the execution of the construction of the new iron and steel works that decisions made thereon shall be subject to the approval of higher officers, … Therefore, it is presented hereby that the following personnel be assigned to a part-time engagement… JU Fifth Rank Doctor of Engineering, Hanroku Yamaguchi to be

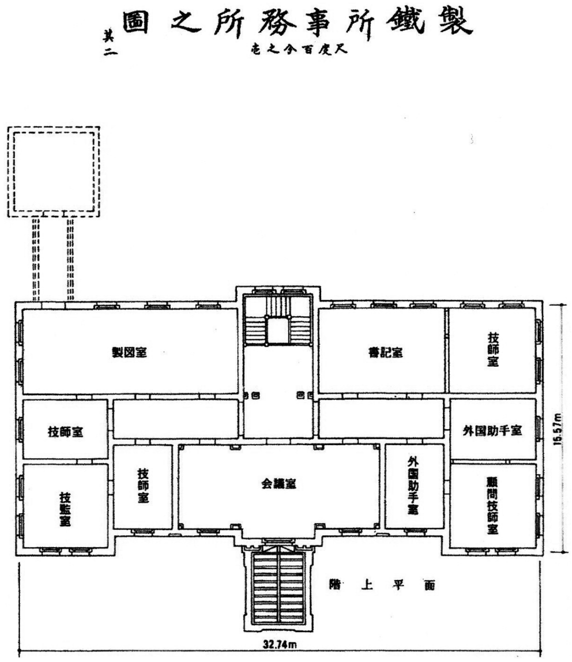

Fig. 8 Second floor plan of First Head Office [5]

Photo 6 First Head Office

entrusted with the architectural construction work of the steel works” and further, there is also a description in the document dated December of the same year [9], “He is engaged in the actual work such as developments of measurement plans and design drawings of various buildings”. This seems to indicate a connection between the construction work and the architect Hanroku Yamaguchi from the Meiji era. He died in 1900. Therefore, his work was conducted in his last years.

3.3.2 Structural form

The building wall is of red brick masonry (English bond masonry using as a unit a block of two bricks placed lengthwise with a header brick of a thickness of half of the length) and the foundation consists of the red brick arch and pine tree piles (Fig. 5), and the roof truss is a wooden queen post truss.

3.3.3 Specification

The building is roofed with Japanese roofing tiles and the ceiling and the inner wall are finished with a wooden lathe and plaster, and the floor is finished with wooden boards.

3.3.4 Building characteristics

The building has bilateral symmetry with a dome built in the

Photo 7 Ceiling garnish in First Head Office

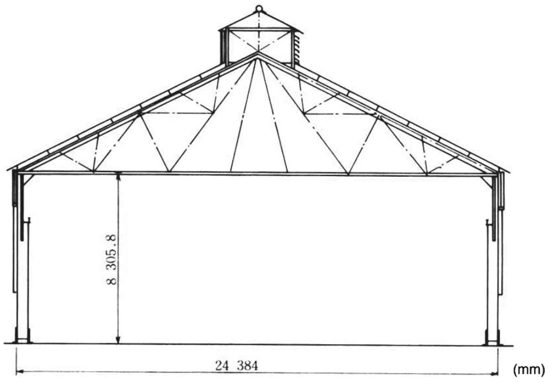

Fig. 9 Drawing of Plate Mill figure [5)]

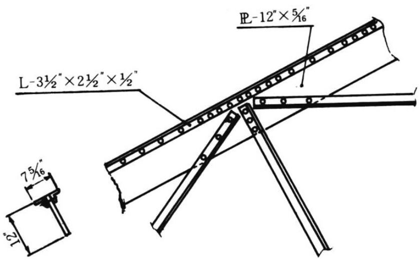

Fig. 10 Details of upper chord member for truss in Plate Mill [5)]

center. The upper side of the window on the first floor is semicircular in shape while the window on the second floor is rectangular in shape, providing a difference in the outlook. A belt of white granite is arranged around the building at the height of the “lintel” of the window. The interior is plaster-finished and a plaster-finished decoration is arranged in the center of the ceiling of the central meeting room on the second floor, providing a decorative counterpoint to the simple interior finish (**Photo 7**). As a whole, the building gives the impression of simplicity and smallness for a general-director's office room with a dignified air.

4. Factory Buildings after Start of Operation 1904–1906

As all of the German engineers returned home in February 1904, the construction of the factory buildings afterwards was undertaken by Japanese only. As the section to take charge of the construction of factory buildings, the first installation subsection was elevated to the engineering section (Shosaku Ono) in February 1904, which was mainly composed of mechanical engineers, and was installed in the engineering department, thus reinforcing the organization for promoting construction. The operation of the engineering section pertaining to the construction of factory buildings covered almost the entire range of construction work such as centering, building of the foundation, fabrication of the steel frame, erection, roofing, brick masonry and so forth. It is reported that many professionals such as steeplejacks, sheet metal workers etc. were employed by the organization [10)].

Despite such circumstances, there were still two examples of factory buildings designed by enterprises in the USA and Britain in Yawata during 1904–1906.

4.1 Plate Mill

One of them is the Plate Mill that started operation in 1905. The building measured 24.4 m wide in span, 195 m long in ridge direction and 8.3 m high in eave height. The roof of the building was of a triangular shape and the corrugated steel sheets were used for the roof and the wall material. The mill building no longer exists (**Fig. 9** [5)]).

4.1.1 Design

The building was designed by the Morgan Corporation in the USA. In the drawings, the position and the settlement of the steel material joints are described in considerable detail. The hallmark on the steel material confirms it is produced by the Carnegie Corporation in the USA.

4.1.2 Structural form

The roof truss is of the fink truss type and as the central part of the lower chord member of the truss becomes long, the part is suspended by the two diagonal members from the top of the truss. A stay is installed to the roof truss end to enhance the rigidity of the end of the principal rafter in a manner different to that of other factory buildings (Fig. 9). Furthermore, this building is characterized by the upper chord member of the roofing truss. The upper chord is a T section-shaped member built with two angle steels (2L–3.5 inch × 2.5 inch × 0.5 inch) and a steel plate (5/8 inch thick × 12 inch wide) (**Fig. 10** [5)]), to which the diagonal members are rivet-joined. This is considered to be the predecessor of the T section steel developed later on. With this design, the steel plate that joins members (gazette plate) as used in the G·H·H design became unnecessary. Although the steel material weight increases slightly, it is advantageous in that labor is reduced. Therefore, the intention of the design seems to be reduction of the labor cost, rather than the steel weight.

4.2 Wheel Shop

Another example is the Wheel Shop that started operation in 1906, which consists of two buildings, each attached to the other measuring 17 m wide in span, 96 m long in ridge direction and 12 m high in eave height. Corrugated steel sheets are used for the roof and the wall material of the buildings, which still exist with a triangular roof type (**Fig. 11** [5)]).

4.2.1 Design

The building was designed by Jackson Corporation in Britain. Although the steel material manufacturer is unidentified, the hallmark 34 of PИ–34 stamped on the steel material corresponds to 34 cm. As, different from the inches used for the dimension of the building, centimeters are used for the steel material, it is considered that the steel materials were imported from another country for the design of an enterprise in Britain.

4.2.2 Structural form

Although the roof truss is of the fink-truss type, the remarkable issue from the structural viewpoint is that the position of the face of the roof truss does not match the position of the column. In other words, the columns are tied to each other by a beam on which the

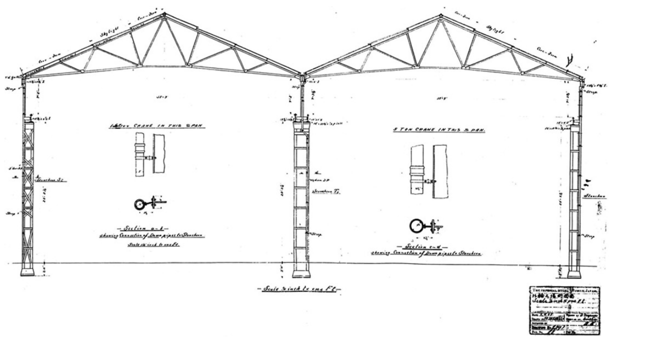

Fig. 11 Drawing of Wheel Shop [5)]

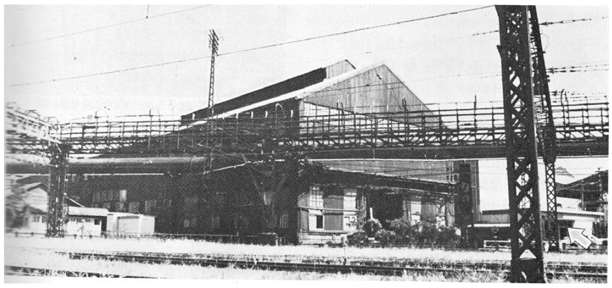

Photo 8 Roll-turning Shop [11)]

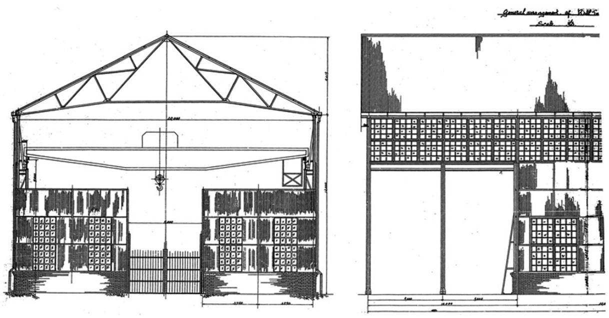

Fig. 12 Drawing of Roll-turning Shop [5)]

end of the roof truss is placed. A flat bar is used as a tension member for the lower chord of the roof truss. However, the rigidity of the structure other than that of the truss face is extremely low and legend has it that the erection was quite difficult because, upon erection, the lower chord was compressed and deformed when the truss was lifted at its top. Stays of a round bar with a large diameter are installed from the eave for reinforcement, which are presumed to have been installed to enhance the rigidity that was insufficient to withstand the vibration that occurred during operation.

Common to these two buildings, the building drawings were delivered as part of the entire set of drawings of mechanical equipment including rolling mills. This fact verifies that the factory building was treated as a part of the plant equipment.

5. Factory Buildings Designed and Constructed by Japanese Engineer

5.1 Roll-turning Shop

After German engineers returned home, Japanese engineers were recruited and exceptional engineers joined the engineering section. Under such circumstances, the first steel frame structure factory building was completed in 1909, wherein the entire process of design, procurement of steel materials, fabrication and erection was executed by Japanese engineers for the first time. Thus the Roll-turning Shop was constructed (**Photo 8** [11)]).

The building measured 20 m wide in span on the gable face, 10 m × 11 spans = 110 m long in ridge direction, 12 m high in eave height with a crane upper surface height of 9 m. The roof and the wall finish materials were corrugated steel sheets and the total floor space was 2200 m^2. The building was dismantled and no longer exists (**Fig. 12** [5)]).

5.1.1 Designer and his background

The designer was Akira Kageyama. He graduated from the mechanical engineering course of the science & engineering department of Kyoto Imperial University in 1906. After working for Kansai Railways Co., Ltd., he joined the Yawata Iron and Steel Works in 1907 and served as a manager in a factory and a manager in design in the engineering section of the engineering department of the Yawata Iron and Steel Works. There were 7602 workers in the steel works in 1908 and 1000 of them belonged to the engineering section [12)], indicating the organization for constructing factory buildings was significantly large. Akira Kageyama wrote in his memoir as follows [13)]: "Our technical seniors in the Works were concerned about our design ability. However, I attended the lecture on architectural structure at the university and I finished the design by referring to the knowledge I acquired through the lecture. By meticulous strength calculation I was able to build the new building", "I studied extensively, seeking books and magazines in our country and abroad", and "By taking advantage of my business trip, I visited the science & engineering department of Kyoto Imperial University and implored them to impart their knowledge". It is exciting to know that, within less than two years of starting to work in the engineering section of the engineering department of Yawata Iron and Steel Works, a mechanical engineer took charge of the design of the steel frame structure factory building and completed it for the first time in our country. This indicates the high level of education at that time.

It is presumed that, behind the scenes, his work was favored by a series of articles about the full-scale design method of steel structures. The series was started in 1905 and was published in an architectural magazine by Tadahiko Hibi, a professor of the civil engineering course of the science & engineering department of Kyoto Imperial University, after his return from studying in Germany and France.

5.1.2 Structural form

Although the loading conditions are not known as there is no documentation on structural calculation available, the structural model is the same as that of the Repair Shop designed by G·H·H wherein the upper end of the column and the principal rafter edge are assumed to be pin-joined. The roof truss is of the fink-truss type and similar to the roof truss types of the Wheel Shop designed by Jackson Corporation in Britain and the model introduced by Tadahiko Hibi in an architectural magazine (**Fig. 13** [14)]). The shape of the lower column that supports the crane runway girder is similar to that of the building of the Repair Shop designed by G·H·H wherein four channel steels are used as the main material and the diagonal braces are installed all in the same direction (**Fig. 14** [5)]). This indicates that he constructed the then existing factory building and the model using the architectural magazine as a reference.

5.1.3 Used steel material

The following steel materials were used: equal angle steel and unequal angle steel for the principal rafter, Z-shaped steel for the purlin, channel steel and unequal angle steel for the upper column, channel steel and equal angle steel for the diagonal brace for the lower column, channel steel for the horizontal member, and T-shaped steel, Z-shaped steel and equal angle steel are employed for the furring strips. Meanwhile, the crane runway girder is a built-up beam consisting of four unequal angle steels with two on the upper side and two on the lower side as the flange and the plates as the web of the beam. These steel materials are listed in the products catalogue [15] of the time as a matter of course. In 1909, some years after the start of operation, the production had increased and the product range had been expanded, generating greater freedom in the choice of member materials. Furthermore, it is stated in the same product catalogue, "The strength of the mild steel (for rivet material, building material, bridge material) is specified as 37.8–42.5 kg/mm^2 (370.69–416.78 N/mm^2)". This shows that steel materials that do not differ greatly from the previous common steel were produced.

Moreover, the nominal steel size of Yawata was shown in inches as described in the products catalogue, "The profiles and the dimension of the products are shown in inches and feet, based on the British standards, provided however, that kilograms are used for weight". Therefore, although the dimensions on drawings are indicated in millimeters, the dimensions of steel materials are shown in inches.

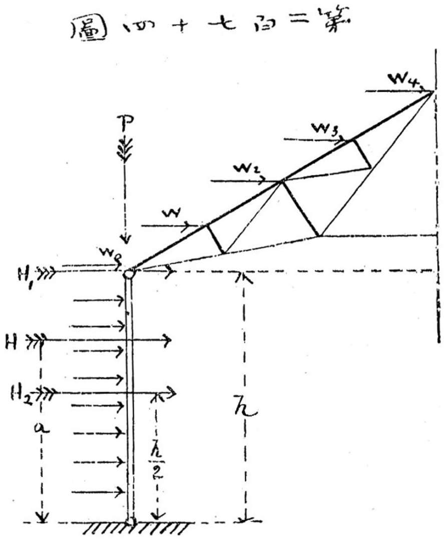

Fig. 13 Drawing of fink-truss in an architectural magazine figure [14]

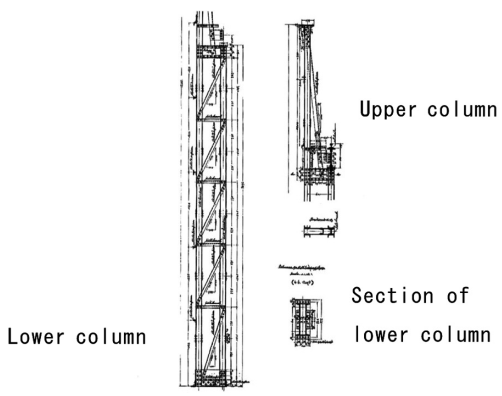

Fig. 14 Detail of column in Roll-turning Shop [5]

5.2 Onga River Water Resource Pumping Station

In addition to the aforementioned Roll-turning Shop, although not steel-structured, another factory building designed by Japanese engineers emerged at the same time. The Onga River Water Resource Pumping Station was completed in 1909 and this too was designated as a UNESCO World Heritage site in 2015 (**Photos 9, 10**).

The building measures, on a wall dimension basis, 22.13 m (72.59 ft) wide in total span length of the two buildings on the gable face, 37.87 m (124.23 ft) long in ridge direction and 7.35 m (24.115 ft) high in eave height. The Pumping Station building consists of two buildings of red brick masonry (slag brick is used in part) attached together. The roof material is corrugated steel sheets and the roof truss is a steel frame of the fink-truss type. The building is still in service as the Onga River Water Resource Pumping Station (**Fig. 15** [5]). The inside dimension between the walls on the gable face of one of the buildings is indicated as 8.53 m (28 ft) and the other one, as 12.19 m (40 ft) in drawings.

5.2.1 Designer

As the design drawing is signed with the name of Funabashi in its designer's signature column together with the date of SEP.16th. 08, and based on the description in a document stored by the Yawata Works Historical Materials Office, in the document of "Appointment of junior officials as follows, the 41st year of Meiji", it is written, "Kiichi Funabashi is to be entrusted with the construction work of the Works… 31st of October, the 41st year of Meiji". Therefore, it is considered that Kiichi Funabashi was the designer. Kiichi Funabashi served in the Ministry of Agriculture & Commerce in 1896, was employed by the Yawata Iron and Steel Works in 1897 and engaged

Photo 9 Onga River Water Resource Pumping Station

Photo 10 Interior of Pumping Station

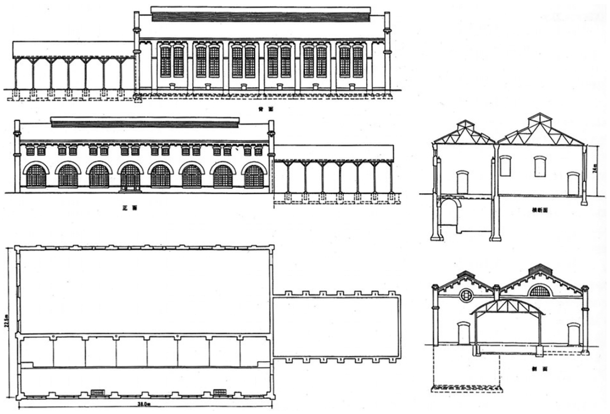

Fig. 15 Drawing of Onga River Water Resource Pumping Station [5)]

in the construction of Yawata at the start of operation. Later, he studied in the USA on his own terms, and after engaging in design work there, he returned to Japan in February, 1908 and opened an architectural practice in 1909. This indicates the design work of the said factory was entrusted to him immediately after his return to Japan. Although the reason is unclear, it is considered as a matter of course that his involvement helped in the construction of Yawata at the start of operation.

As the major work of the people involved in architecture in Yawata at the time of foundation covered the design and construction of the office and the official residence, presumably he was engaged in the design and the construction of the former First Head Office in one way or another. As this building is of red brick masonry, the design of this building may be viewed as the upgraded design of the former First Head Office.

5.2.2 Structural form

The building is of red brick masonry (slag brick is used in part) with a roof truss of the steel frame fink-truss type mounted on the brick wall.

5.2.3 Building characteristics

On the exterior side of the wall where red bricks are mainly used, at the corner of the wall, for the waist-high wall and around the upper round window periphery, white slag bricks are used seemingly to imitate and substitute granite. The interior has a church-like design, employing an arch design and giving a highly noble feel to the factory building. The dimensions in the drawings are indicated in inches, with which Kiichi Funabashi may have wanted to show the knowledge he had acquired in the USA. The steel frame roof truss is of the orthodox fink-truss type, wherein a part of the technology employed in the USA at that time is witnessed (Photo 10).

6. Factory Buildings 1916–1920 (Early Taisho Period)

In the second stage expansion project of Yawata that started in 1906 to handle the growth of the steel demand in our country, the major factories were the No. 2 Steel Making Plant, No. 3 Blooming Mill, No. 2 Medium Section Mill, No. 3 Small Section Mill and No. 2 Plate Mill. The project is characterized by the design of the buildings of the No. 2 Steel Making Plant and the related factories being entrusted to G·H·H once again. In this period, despite the actual achievements in the design and completion of factories in Yawata at its own responsibility in 1909, the continued dependency on foreign countries had to be maintained for the following reasons. First, reliable architectural technology of a large-scale plant such as a steel-making plant had not been established. Second, Akira Kageyama who was the key person had already been in the position to supervise the entire construction, and was not in a position to conduct the design alone, and third, there were no appropriate personnel who could succeed his work. However, this was the last case of dependency on foreign design.

Meanwhile, although slightly different in nature from these production plants, the Doyama Fabricating Shop that belonged to the organization of the engineering section was expanded in 1917. Its design was conducted not by Akira Kageyama, but by a mechanical engineer, Takashi Kataoka.

Hereafter, the characteristic features of design are stated based on the examples of the No. 2 Steel Making Plant and the No. 2 Plate Mill.

6.1 No. 2 Steel Making Plant

The building measured 19.55 m wide in the central span on the gable face, 18.646 m high in eave height with a crane upper surface height of 13 m. This was a large-scale building with corrugated steel sheets used as the materials of the roof and the wall-finish material. This building was dismantled and no longer exists (**Fig. 16** [5)]).

6.1.1 Design

It was designed by G·H·H, the same company that designed the No. 1 Steel Making Plant (**Fig. 17** [5)]) built at the time of the start of operation. When compared with that building, the design of the round-shaped roof was changed to a design type consisting of straight lines.

6.1.2 Structural form

The structure was based on the king post truss type and there was no particular change from the conventional form. The details of this factory building are very similar to that introduced in the technical book by the German author Bleich that had been used as a textbook until around the early 30s of Showa. Millimeters are used in the design dimensions similarly as before, and in conjunction with this, centimeters are used with the German steel material. The rea-

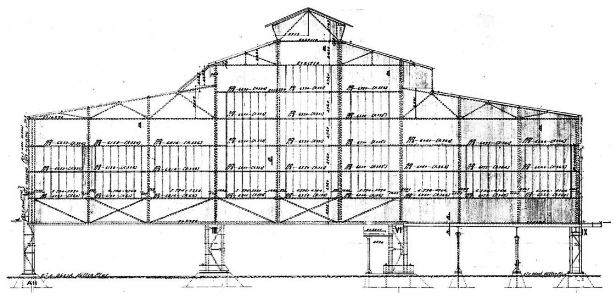

Fig. 16 Drawing of No. 2 Steel Making Plant [5)]

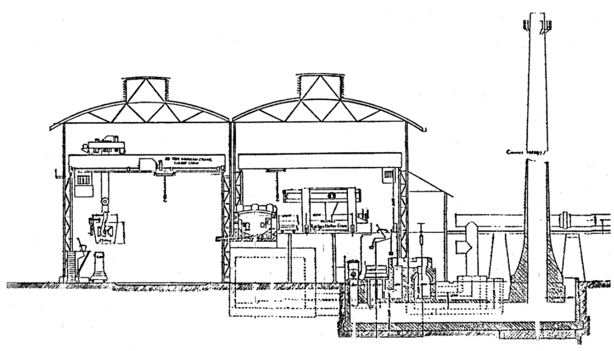

Fig. 17 Drawing of No. 1 Steel Making Plant [5)]

sons why Yawata steel material was not employed is that the design was made on the premise of the use of the company's own steel products and that, in part, the steel material of Yawata was based on inches. In the year 1916 when the plant was completed, the structure had become very large as indicated by the eave height of 20 m, and the number of rivets had increased. Simultaneously, the accuracy of the rivet work was enhanced and the No. 2 Steel Making Plant resembled a masterpiece of rivet work. However, the plant was dismantled and no longer exists.

6.2 No. 2 Plate Mill

The building measures 17.5 m wide in span on the gable face, 8.4 m high in the crane upper surface height and the roof and the wall finish material were corrugated steel sheets (**Fig. 18**[5])).

6.2.1 Design

Although in most cases the design was entrusted to foreign plant manufacturers conventionally from the viewpoint of procuring the whole of the plant as one package, the design of the building of the No. 2 Plate Mill was entrusted to the domestic Yokogawa Komusho in 1920. This indicates the shortage of human resources of Yawata at the time and the growth of the domestic technological capability. Furthermore, inches were used to indicate all dimensions of the building.

6.2.2 Structural form

Judging from the drawing, a unique structural form is employed that is characterized by a knee brace member that is suspended from the principal rafter and supported by a large truss beam. On the other hand, the height of the upper chord member of the roof truss is enlarged and the gazette plates are omitted. This design is very similar to the design of the building of the Plate Mill designed by the Morgan Corporation in the USA that started operation in 1905 (**Fig. 19**[4])). This is further evidence that the American design technology acquired by Tamisuke Yokogawa had been inherited as the technology of the Yokogawa Komusho and was utilized for the design of the building of the No. 2 Plate Mill.

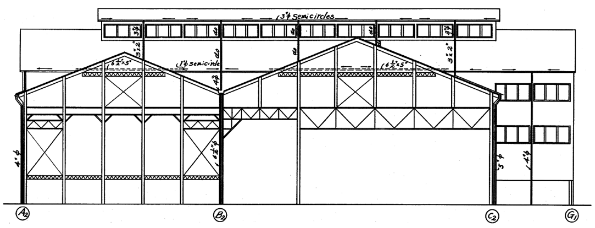

Fig. 18 Drawing of No. 2 Plate Mill[5])

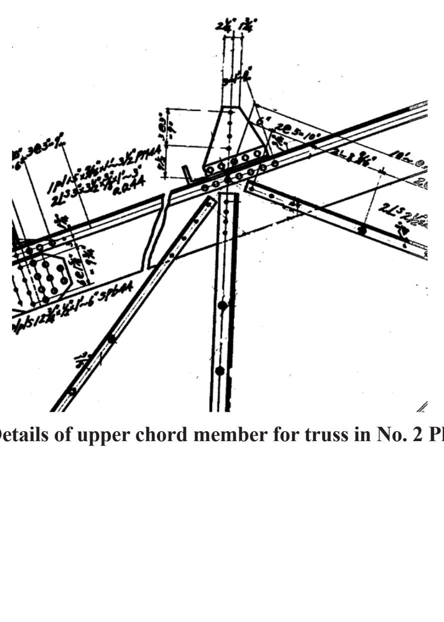

Fig. 19 Details of upper chord member for truss in No. 2 Plate Mill[4])

7. Factory Buildings 1919–1925 (Later Taisho Period)

From 1914, the third stage expansion project was promoted. The target mills for construction were the No. 3 Steel Making Plant, the Nos. 4–6 Blooming Mills and the No. 2 and the No. 3 Large Section Mills. Similar to the second stage expansion project, the project covered a steel making plant and large section mills, and the project consisted of the construction of large-scale factory buildings.

In the second stage expansion project, the construction was executed based on the then existing conventional construction organization and the utilization of the foreign enterprises. However, in the third stage expansion project, there was a distinct attitude of executing the entire structure from design to erection based wholly on the domestic technologies. Specifically, a project organization designated as the provisional construction headquarters was established[16]). However, as the organization consisted mostly of engineers holding two posts concurrently, most belonging to other existing sections, the recruitment of engineers from sources outside the steelworks was pursued.

7.1 Securing architect engineer resources

In 1916, although engineers were usually employed in the capacity of assistant engineer (junior officer), three engineers from the Yokogawa Komusho, Tomikichi Takeda and Saburo Hamano, were employed directly as engineers (senior official) and Kiichi Murakami was employed as the assistant engineer (junior official). Tomikichi Takeda was appointed as the design chief and in 1919, he was appointed as a steel frame structure design chief and as the chief of design of the official residence and the affiliated hospital. Although the time of assignment is unknown, he also assumed the post of manager of the architecture section as an additional office.

Documents clarifying the reason for the recruitment from the Yokogawa Komusho are not available, probably because the company already had experience in executing the design work for the No. 2 Plate Mill in the second stage expansion project of Yawata and the company had a prominent ensemble of exceptional engineers in Japan.

7.2 Status of mechanical engineers' human resources

The leading person in the steel structure architectural design in Yawata during the period from 1907 (the 40th year of Meiji) to around 1912 (early Taisho period) was Akira Kageyama. As successors to him, several mechanical engineers are listed. They took charge of the design of the steel frame structures like those of the blast furnace support structure and the design of the expansion work of the Doyama Fabrication Shop.

7.3 Design work allocation between architect engineer and mechanical engineer

Around 1916, each organization vied with each other for work, and capable engineers took charge of it under such a situation. For example, while mechanical engineers designed factory buildings, Tomikichi Takeda, an architect engineer, designed the support structure of the No. 6 Blast Furnace. The allocation of work depended largely on the individual with the work being entrusted to the division with the most capable engineers[17]).

Hereunder, the characteristic features of their design are stated based on the examples of the No. 3 Steel Making Plant and the No. 6 Blooming Mill that they designed.

7.4 No. 3 Steel Making Plant

The first steel making plant in Yawata that was domestically designed is the No. 3 Steel Making Plant completed in 1923. The building measures 20 m wide in span on the gable face, 104 m long in ridge direction and 17.539 m high in eave height with a crane up-

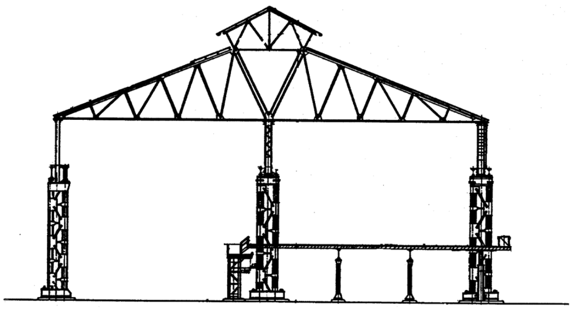

Fig. 20 Drawing of No. 3 Steel Making Plant [5)]

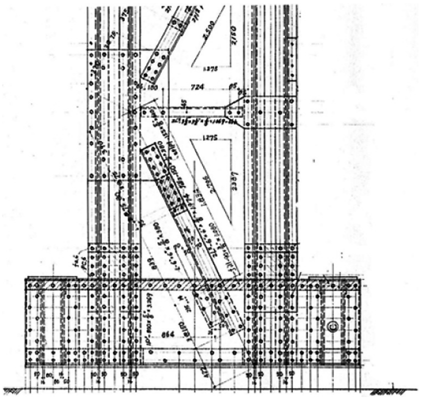

Fig. 21 Detail of column base in No. 3 Steel Making Plant [5)]

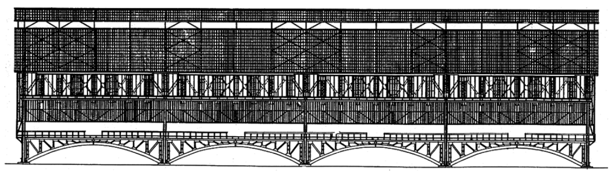

Fig. 22 Arch elevations of No. 3 Steel Making Plant [5)]

per surface height of 13 m. The roof and the wall finish materials were corrugated steel sheets (**Fig. 20** [5)]).

7.4.1 Design

As the drawings indicate Murakami as the designer and Takeda as the approver, the design was conducted by members from the Yokogawa Komusho. Drawings show the details of a very sophisticated rivet-structured column (**Fig. 21** [5)]), indicating the level of design was enhanced. Although inches were used for the steel materials as they were domestically produced, millimeters are used for the dimensions in drawings.

7.4.2 Structural form

The roof truss has a truss structure. As other characteristic features, to support the working deck, the arch structure is employed instead of the conventional support columns installed between the main columns (**Fig. 22** [5)]). There was an obvious need for building a large space.

7.5 No. 6 Blooming Mill

The building measures 26 m wide in span on the gable face, 78 m long in ridge direction and 16.5 m high in eave height with a crane upper face height of 13 m. The roof and the wall finish materials were corrugated steel sheets.

7.5.1 Design

The drawing dated May, 1920 (the 9th year of Taisho) has the

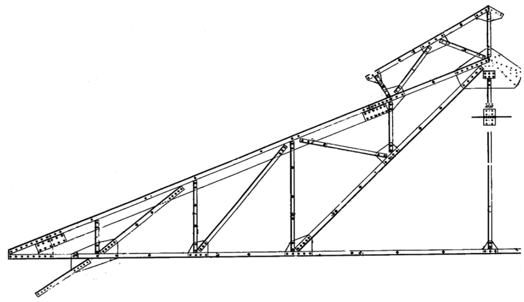

Fig. 23 Roof truss for No. 6 Blooming Mill [5)]

signatures of "Isao Mitsunaga" as the designer, and "(Tomikichi) Takeda" as the approver. Isao Mitsunaga graduated from the civil engineering course of the engineering specialty department of Tohoku Imperial University in 1919, and it is known that engineers with design capability other than Tomikichi Takeda and Kiichi Murakami were present. However, as the new graduate from the university was a civil engineering engineer, and not an architect engineer, this reconfirms that the work allocated to the architect engineers was the construction of office buildings as well as factory buildings.

7.5.2 Structural form

As the building is of a large-scale with a span length of 26 m, the roof truss is of a statically indeterminate fink-truss type with the knee brace member (**Fig. 23** [5)]).

The characteristic features common to the factory buildings stated so far including the No. 3 Steel Making Plant are as follows.

(1) Many of the roof trusses are of the fink-truss type. Incidentally, all of the roof trusses of the Plate Mill buildings designed by an American enterprise and built in 1905, the Wheel Shop designed by a British enterprise and built in 1906 and the Roll-turning Shop designed by Akira Kageyama in 1909 are of the static fink-truss type, albeit slightly different in form.
The advantageous feature of the fink-truss is the shortened compression materials of the upper truss chord members [18)]. The upper chord members (compression members) can be shortened in the fink-truss type by providing diagonal members across the contact points with the compression members. This truss type was widely employed at that time to prevent the occurrence of the eccentricity and/or buckling that occur when unsymmetrical angle steel is used.

(2) The roof truss of a statically indeterminate structure emerged. Its emergence is attributed to the gradual growth and emergence of larger scale buildings, which led to non-compliance with the requirements for static structure, and simultaneously, the truss stress calculation technique also made progress, enabling analysis of the statically indeterminate truss.

(3) In the later Taisho period, Yawata products were used for all of the steel materials. The unit of measurement used for the dimensions in drawings was millimeters. However, as inches were used as the measurement unit for Yawata products, the member materials were indicated in inches.

(4) Judging from the drawings, the design of columns became very sophisticated. This is considered to be attributed partly to the abundant variety of steel materials.

8. Factory Buildings 1933–1935 (Early Showa Period)

All of the factories and plants were completed before 1925. However, Tomikichi Takeda and Kiichi Murakami retired or were

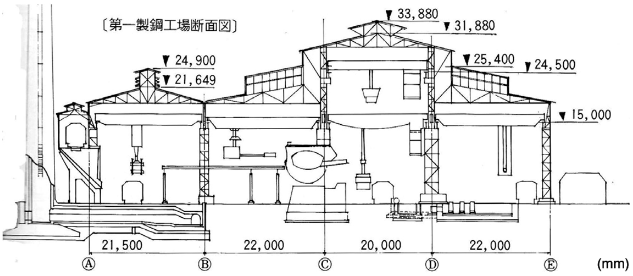

Fig. 24 Drawing of New No. 1 Steel Making Plant [20)]

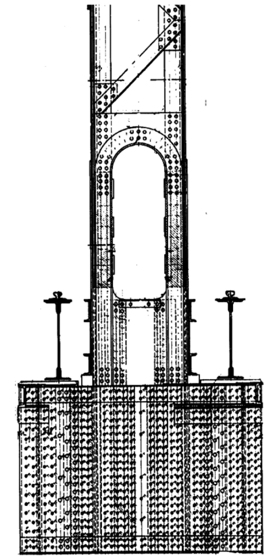

Fig. 25 Details of upper column in New No. 1 Steel Making Plant [5)]

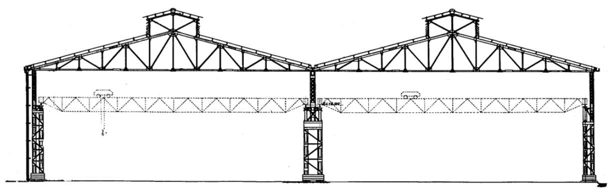

Fig. 26 Drawing of Finishing Mill [5)]

transferred to another ministry in 1921, and did not see them through to completion. Due to the exit of Tomikichi Takeda and Kiichi Murakami, there were no architect engineers with the design capability of steel frame structure buildings in Yawata for some time afterwards. The following quote illustrates this situation: “Generally, architect engineers didn't show any interest in factory buildings preferring to work primarily on the official residence and the welfare facilities” [19)].

Although the construction of the factory buildings slumped drastically afterwards, in 1935, the New No. 1 Steel Making Plant and the Finishing Mill were completed simultaneously. However, as there were no architect engineers with the capability of designing factory buildings, the design was left to the civil engineering engineers. This indicates that the design of factory buildings was transferred to civil engineering engineers from architect engineers, including the factory building of the New No. 1 Steel Making Plant.

8.1 New No. 1 Steel Making Plant

The building measures 26 m wide in span on the gable face, 78 m long in ridge direction and 16.5 m high in eave height with a crane upper surface height of 13 m. The roof and the wall finish materials were corrugated steel sheets (**Fig. 24** [20)]).

8.1.1 Design

The designer of the New No. 1 Steel Making Plant, Yasuichi Watanuki (graduated from the civil engineering course of the technological department of Kyushu Imperial University in 1919), described the background to the design in the following discussion meeting [19)]: “Drawings of the Showa Seiko were forwarded to Tokyo, and I borrowed them and used them as a reference”, “As architect engineers were working on wooden architectures” and “Civil engineering engineers were working on bridges, I felt like I was working on a relative”.

The drawing of the New No. 1 Steel Making Plant of 1933 (the 8th year of Showa) shows the names of “Taizo Inoue” and “Shinji Inoue” as the designers. They were the engineers employed in the capacity of “hired engineer” after graduating from technical high school and they were engaged in the actual work. It is known that, around 1933, engineers who executed actual design work had increased in number.

In the architectural drawing, the stress diagram of the roof truss developed by graphical analysis is described, which conforms to the form of the design drawings of bridges. The designs are highly detailed. As the plant was large in scale and there were so many rivets, it is considered that around 1933, the rivet structure system had reached the level of perfection in design and construction.

As one of the characteristic features of the building, a space allowing the passage of a person is provided in the upper column above the crane upper surface (**Fig. 25** [5)]). Yasuichi Watanuki later stated, “This annoyed me very much [19)]”.

8.2 Finishing Mill

The signatures in the drawing of 1933 indicate that the construction was promoted under the same organization as that for the New No. 1 Steel Making Plant. As for the building, the roof truss has a relatively orthodox structure of the king post truss type (**Fig. 26** [5)]).

9. Conclusion

The transition of the design of the factory buildings in Yawata from the start of operation in 1901 until the construction of factory buildings in the early Showa period is described. The design relied on German technology at first and then, triggered by the design and construction of factory buildings by the company itself in 1909, foreign technologies no longer had to be relied upon, and domestic internal design was enabled by utilizing the domestic civilian technologies of the Yokogawa Komusho and so forth that specialized in designing steel structures.

The transition similarly shows the process of how the design of the factory buildings in Yawata, which had been undertaken by mechanical engineers until then, was transferred to the architect engineers and the civil engineering engineers along with the development of the architect design technology.

The transition of the design of factory buildings up to around 1935 in the early Showa period is also described. Thereafter, from around 1940 (middle of the 10s of Showa) up to the present day, (the days of the Imperial Yawata Steel Works to the inauguration of the Japan Iron & Steel Co., Ltd.), the design of factory buildings was entrusted to architect engineers.

This article was written with reference to the following materials. “A Study on the Introduction and Development process of the Steel structure building in Japan. 2009”, “A study on the design and construction of steel structure architecture in the Japanese government control Yawata Steel Works from the foundation period to the early period of Showa. Journal of Kyushu Kyoritsu University Research Center. 2008" and "Visit to the Heritage of Industrial Modernization — Industrial Heritage Facilities of the Imperial Yawata Steel Works — Tsuchikikai 50th anniversary memorial booklet. 2015".

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