Technical Report

UDC 662 . 741 : 658 . 28

Low-Cost and Short-Term Construction of Temporary Buildings for Coke Ovens

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Abstract

The coke oven, which is a major facility in a steel plant, has a life span of approximately 40 years, and its operation level plunges when nearing its end. Many constructions and restorations of coke ovens are scheduled in the near future to act on coke production cut backs, and low-cost, short-term construction is an important challenge. This can be achieved by determining the required functions and space and revising the shape of the temporary building for the furnace installation, which is a critical pass in coke oven construction. Application of a movable roof and utilization of coke oven equipment minimized the space of the temporary building, and enabled 150 tons reduction of steel and a 30 days reduction in construction time compared to conventional designs.

1. Introduction

Nippon Steel & Sumitomo Metal Corporation has developed a system in which their own facility engineers plan, design, and build steelmaking facilities. In this system, civil engineering and construction engineers manage the structures of which they have charge, evaluating the functions necessary for these structures, reviewing given conditions such as operating methods, machine load, and facility layout, and planning and designing the structures that sometimes require the design change of another facility component and consideration of the necessity of a plant building. This system has allowed for the pursuit and implementation of structures and construction methods for civil engineering and construction facilities, providing a strict balance between the achievement of the required performance in a reliable manner and low-cost/short-term construction.

This report introduces the development of technology and initiatives for low-cost and short-term construction of temporary buildings which are built for the installation of new coke ovens or the renewal of existing ones. In addition, this report describes the next generation temporary buildings that have been developed by reviewing the functions required for plant buildings.

2. Features of Coke Oven Temporary Buildings

The majority of the coke ovens owned and operated by Nippon Steel & Sumitomo Metal for more than 36 years (average oven age 41.5 year) have started to age. Furnace throats have narrowed and holes in bricks have been observed in these old ovens, significantly deteriorating the operation level. As a measure to respond to the reduction of coke production due to aged existing coke ovens, numerous coke ovens have been installed and renewed to date. Installation and renewal plans are also to be implemented going forward.

As shown in **Fig. 1**, a coke oven consists of a brick-made oven, backstays for fastening the oven, platforms used for oven maintenance work and on which a mobile unit moves, etc. On the top and sides of the oven, there are pipes or a mobile unit. A temporary building for coke ovens, which is built when an oven is installed or

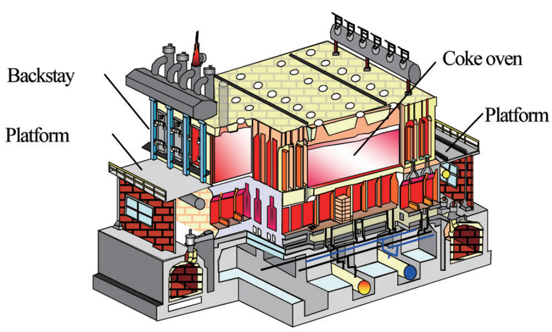

Fig. 1 Overview of coke oven

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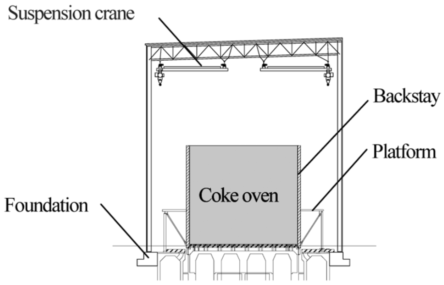


Fig. 2 Temporary building for coke oven

renewed, has functions to prevent the oven from being waterlogged by rain during the period from oven building to drying, and to support the suspension crane for hoisting and installation of peripheral facilities of the oven. As shown in **Fig. 2**, a temporary building encases the overall coke oven. A temporary building is required only for construction of the oven itself, and is to be used for a term not exceeding one year. The construction and removal processes are critical in the construction of a coke oven and account for about 20% of the overall construction period. For this reason, low-cost and short-term coke oven construction are particularly important issues.

3. Conventional Method of Low-Cost and Short-Term Construction

As the initiatives for low-cost and short-term construction of temporary buildings for coke ovens that have been implemented to date, labor saving in the construction and structural volume reduction as shown in **Fig. 3** have been examined and embodied.

3.1 Application of wire element

Wire diagonal bracings were provided in the crossbeam (side) direction on the temporary building in order to reduce the horizontal force applied to the framework and to reduce the weight of the temporary building members. **Figure 4** shows the No. 5 coke oven at Oita Works, which was provided with the wire diagonal bracings. Whereas the pared down cross-section of each member allowed reduction of the overall work volume, rain seeped into the parts of the wall where wires penetrated through, making the construction difficult. Also, since wires were placed around the temporary building, the available space for work was limited, resulting in inconvenience including reduction of the lines of flow of construction vehicles and the temporary storage space. As wires may disturb the building construction and machine construction, this method may be used when sufficient space is available around the construction areas and work around the building is not affected by the wires.

3.2 Utilizing pinion wall

Pinion walls, which are installed at both ends of a coke oven to suppress the expansion of the coke oven when operating, are designed against the horizontal force in the ridge beam (longitudinal) direction. It has sufficiently strong structural resistance in the crossbeam direction. Focusing on this point, improvement of frame rigidity on the truss surface and the gable side of the temporary building enabled transfer of the horizontal force in the crossbeam direction to the pinion walls at both ends, and the weight of the members of the intermediate framework was reduced. It has been used in the No. 5 coke oven of Muroran Works and the No. 5 coke oven (**Fig. 5**) of Nagoya Works. Pared down members of the temporary building reduced the amount of steel by about 3%. Although this method increases the number of framework members on the gable surface of

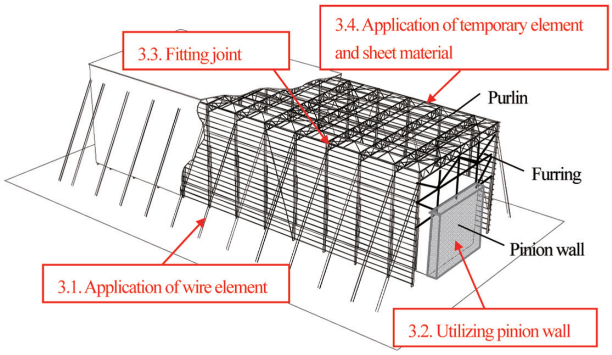


Fig. 3 Conventional method of low-cost and short-term constructing

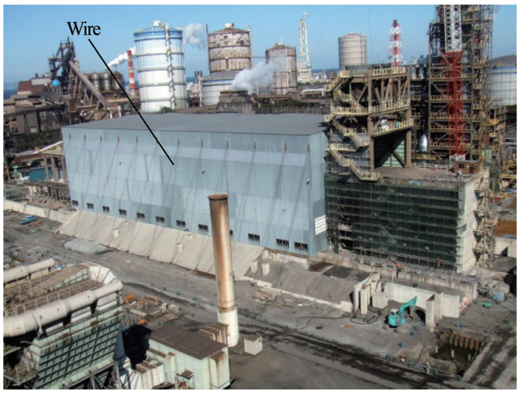


Fig. 4 Application of wire element (No. 5 coke oven in Oita Works)

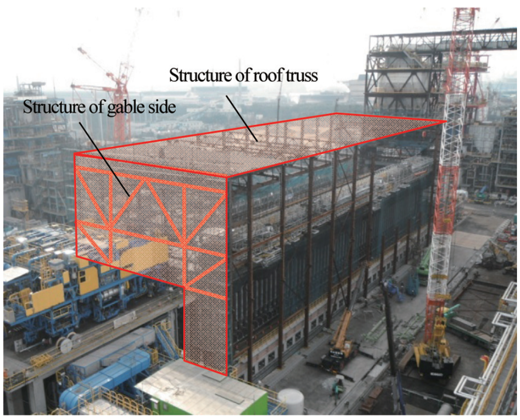


Fig. 5 Utilizing pinion wall (No. 5 coke oven in Nagoya Works)

the pinion wall end, it does not pose an obstacle to other work. It can be applied to most future projects.

3.3 Fitting joint

For the joints of the frame structure, it is necessary to semi-permanently maintain the fastened parts by welding or bolts. Since a temporary building is to be used for less than one year, meeting these joint rules is not necessarily required. Rather, a joint is required to facilitate assembly/removal. In the past, due to rusted bolts that were not smoothly loosened when disassembling temporary buildings, many members were disassembled by gas cutting.

As a new frame joining method that allows for simple assembly/removal, a fitting joining that is completed only by insertion was used. Since joining can be completed only by placing a hoisted steel

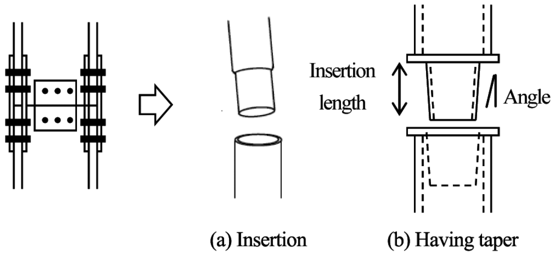


Fig. 6 Detail of fitting joint


Fig. 7 Application of fitting joint (No. 5 coke oven in Nagoya Works)


Fig. 8 Application of temporary element and sheet material (No. 1A coke oven in Wakayama Works)

frame in the joining position, the work period for the construction and removal processes can be shortened. Fitting joining, which uses gravity, is suitable for joining the column joints of temporary buildings.

The mechanical performance required for a joint is to transfer the bending moment. As a method to realize this, a drop-in feature as shown in **Fig. 6** (a) can be used. Considering the workability, a certain amount of clearance is required around the inlet. Therefore, to balance the workability and the adhesion at the joint, a method providing a taper at the fitting joint as shown in Fig. 6 (b) was used. For necessary clearance, the taper angle and insertion length to transfer sufficient load without disengagement of the joint, the performance was checked by element experiments. This method has been used in the No. 5 coke oven in Nagoya Works (**Fig. 7**). When the temporary building is dismantled, internal stress on the fitting joints may make simple removal difficult, requiring gas cutting or other means to dismantle it. This method requires improvement of the dismantling workability.

3.4 Application of temporary element and a sheet material

Since a temporary building is a structure that is used temporarily, the load conditions (wind load, snow load) taken into consideration for the design are reduced when the structure is designed. Also, since application for construction approval is not required for temporary buildings, frameworks can be built using scaffolding members. At the No. 1A coke oven in Wakayama Works, in addition to the use of scaffolding members for the main framework, a sheet material was used for the outside wall in order to save on manpower during the construction and to shorten the construction period (**Fig. 8**). The challenge with this construction method is the improvement regarding the parts finished by means of fastening, overlapping, etc., of the sheets where it is necessary to take measures for the prevention of water entry.

The initiatives implemented so far have involved the improvement of members and frames such as reduction of the member volume, installation of members, and power-saving in dismantling. For further cost reduction and shortening of the construction period, a drastic structural improvement is required. As a new initiative, the building shape, necessary functions, and other design conditions were thoroughly reviewed, from which the development of a more improved temporary building was started.

4. Latest Initiative for Low-Cost and Short-Term Construction

4.1 Viewpoints

The entire coke oven is encased within the temporary building in order to shelter the oven bricks from the rain during construction of the oven and also to support the lifting equipment (suspension crane, etc.) for placement and installation of the oven's peripheral facilities. To devise a more effective method for low-cost and short-term construction of temporary buildings, we started by identifying the factors that determine the shape of a temporary building to reconsider the shape of the facilities consisting of minimum components with necessary functions, thereby improving the construction method at the planning stage.

One of the factors that determine the shape of a temporary building is the lifting height of the suspension crane. In particular, the work regarding members hoisted to the upper part of the oven, which is required only for machine construction after the building of the oven, is limited in duration with many intervals. Given this, the lifting function at the upper part of the oven is substituted by a mobile crane installed using the roof opening and external area, and no suspension crane is used, thereby reducing the building height as much as possible (**Fig. 9**). Regarding opening/closing the roof, various methods were considered. As highly frequent opening/closing any locations on the roof of a temporary building for coke ovens is required to install equipment in the upper part of the coke oven, a roof composed of blocked movable portions that can be individually slid on the top of the building was used (**Fig. 10**). At the coke oven ends, the inspection/repair space for the movable machines that is called the edge deck or intermediate deck is provided for each oven battery. The upper part of all ovens can be opened/closed by sliding each roof block using the evacuation space of the roof blocks above the edge deck.

Next, the width of the temporary building was reviewed. The columns of a temporary building were placed outside the machine structure members that compose the oven in order to be constitutionally separated from the coke oven peripheral facilities (**Fig. 11**).

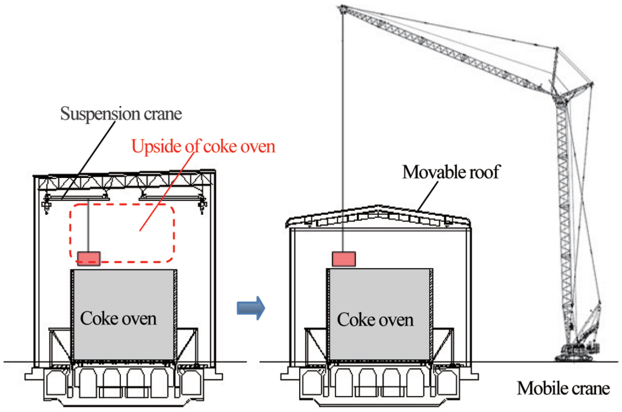


Fig. 9 Alternative approach of suspension crane

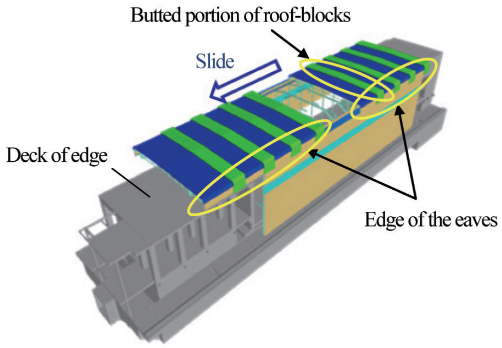


Fig. 10 Outline of movable roof

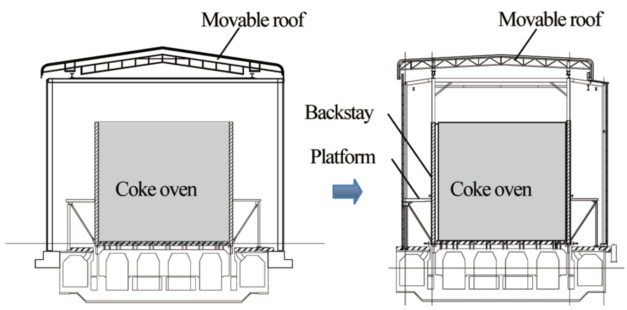


Fig. 11 Composite approach using backstay and platform

Since the backstay (hereinafter referred to as "BS") and platform (hereinafter referred to as "PH"), which are machine structure members, are designed according to the oven expansion load estimation when operating, sufficient design allowance is available during the period of oven building and oven drying when the temporary building is used. In addition, as the building load can be reduced by eliminating the use of a suspension crane, BS and PH were used to assume the role of the main columns of the temporary building to which the major part of the load was applied, thereby reducing the number of building structure members. Figure 11 shows a composite structure image of BS, PH and the temporary building.

From the concept as described above, a new temporary building with the volume ultimately reduced while maintaining the necessary functions was proposed to realize low-cost and short-term construction of temporary buildings for coke ovens.

4.2 Challenges in achievement

While structures with movable roofs are widely used in general, many of the example cases are dome structures, which have usages and opening/closing frequencies that differ greatly from those of temporary buildings for coke ovens. When a movable roof was used for a temporary building, the following technical issues were extracted for consideration.

(1) Waterproof performance of a movable roof

When a movable roof is used for a temporary building, the entry of wind and rain from the clearance between the edges of roof blocks is a concern. The flashing used for movable roofs of dome structures is a high adhesion structure that prevents water from entering by sending pressurized air to the inside using butted hollow rubber tubes, or using combined rubber tubes, gutters, etc. For this reason, it is not suitable for temporary buildings requiring a simple and inexpensive structure. Therefore, the flashing structure for a movable roof used for temporary buildings was examined and the waterproof performance checked.

(2) Operation method of the movable roof

When the equipment for opening/closing the roof is installed on the top of a coke oven in a temporary building for coke ovens, it is necessary to open/close the roof in the entire range above the coke oven and to frequently change the position of the opening about 10 times per day. To speed up the machine construction, the operation method that can provide the opening only in the necessary range in any desired position was examined and the drive unit was designed and verified.

(3) Use of coke oven facilities

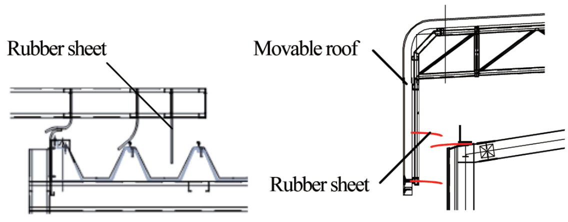
In a composite structure with BS and PH incorporated as components of a temporary building, the addition of the temporary building load can increase the stress applied to BS and PH and in turn increase distortion of these parts. Therefore, a structure model was constructed that satisfies all the required functions for the entire structure, and the structure safety was also verified, thereby demonstrating a new effective structure for a temporary building.

5. Specific Measures for Resolving the Issues

5.1 Waterproof performance of the movable roof

The movable roof must be provided with a water stop line for the clearances between the roof blocks when the roof is closed. Since the area to which the water stop line is applied has the peaks and troughs of a folding roof, a rubber sheet material, which can flexibly conform with the complex shape, is used for the water stop material, rather than the steel sheet accessory normally used for stopping water. When a movable roof is applied to a temporary building to be temporarily used, the roof is likely to be designed with emphasis on the economic efficiency, causing the truss surface rigidity to be low, which may result in a roof block being turned, distorted, or deviated when being slid. Furthermore, in the coke oven construction, the construction area is likely to be narrow, which requires compact roof blocks so that the basic assembly can be performed. As the number of roof blocks used is increased, there will be more joints that require water stop plates. To this end, a flashing structure of a movable roof that is as simple and inexpensive as possible and that can stop water in a position where a roof block is deviated was considered.

Each butted portion of the roof blocks shown in Fig. 10 has an eave-like overhang as shown in **Fig. 12** (a) and has a structure that stops water at the contact point of the rubber sheet with the folding installed under the overhang. This structure does not require ma-



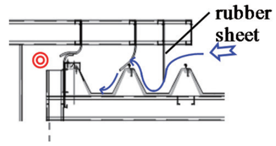
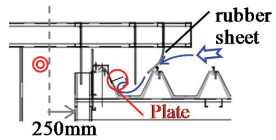
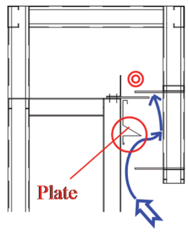
(a) Butted portion of roof-blocks (b) Edge of the eaves

Fig. 12 Weathering of movable roof

(a) Butted portion of roof-blocks (b) Edge of the eaves

Fig. 13 Photo of waterproof test

Table 1 Test result

Case	Thickness of rubber sheet	Plate	Wind velocity (point ◎)	Water-proof
• Butted portion of roof-blocks 	5 mm	–	0.5 m/s	○
	10 mm	–	0.4 m/s	○
• Butted portion of roof-blocks 	5 mm	–	2.2 m/s	×
	10 mm	–	0.5 m/s	○
	5 mm	○	2.0 m/s	○
• Edge of the eaves 	5 mm	○	3.0 m/s	○
	10 mm	○	2.3 m/s	○

chining of the counterpart roof block in the lower part and is very simple. Also, depending on the layout of multiple rubber sheets, water can be prevented from entering when the roof is not completely closed. The edge of the eaves as shown in Fig. 10, which have multiple rubber sheets that are alternately installed inside the wall, work to prevent water from entering from both above and below the clearance between the roof and the wall as shown in Fig. 12 (b).

Wind resistance and water resistance were tested using a partial model in order to verify the reliability of the flashings of the eaves and those between roof blocks. Two groups of test pieces, simulating the flashing between roof blocks and that for eaves, were used. The variables in the test were the rubber sheet thickness, length of the gap between roof blocks, and presence/absence of a water stop plate. For the rubber sheets, a material made of inexpensive natural rubber was selected and sheets used were 5 mm and 10 mm in thickness. The length of the gap between roof blocks was 250 mm from the initial position, considering the turning and deformation of the roof. The photos of the test pieces are shown in **Fig. 13**.

Table 1 shows the test results. When the test pieces between roof blocks are compared to each other, water did not enter the building when the roof was closed regardless of the rubber sheet thickness, showing sufficient waterproof performance. With the test piece taking into account the gap between roof blocks, the 5mm-thick rubber sheet began to float excessively and water entered the building. However, as shown in Table 1, a water stop plate provided to the folding blocked rainwater, and water entry inside the building was not observed. Therefore, when a water stop plate was provided to the folding, sufficient waterproof performance was obtained regardless of the thickness of the rubber sheet. In the movable roof that we actually manufactured, the friction resistance of the rubber sheet when sliding a roof block was approx. 1/2 of the required roof thrust with a sheet thickness of 10 mm and was approx. 1/12 with a sheet thickness of 5 mm. Considering the load on the drive unit to be minimized, the thickness of 5 mm was selected for the rubber sheet between roof blocks.

When the test pieces of eaves are compared, it was confirmed that water did not enter the building and sufficient waterproof performance was shown regardless of the rubber sheet thickness. Although water did not enter the building with the 5mm-thick rubber sheet, the thickness of 10 mm was used for the rubber sheet of the eaves in order to prevent the deflection of the rubber sheet due to the gravity and excessive gap between the rubber sheet and the wall.

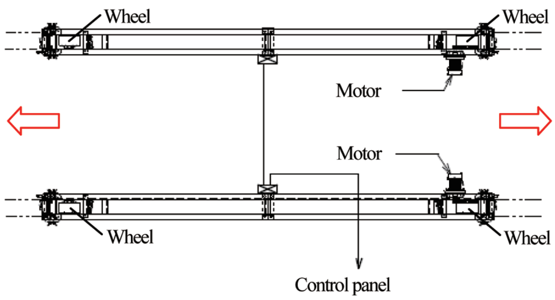
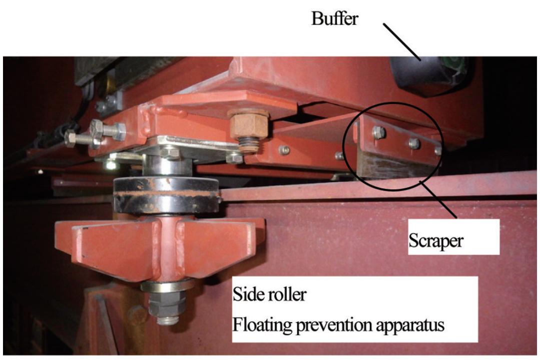


Fig. 14 Layout of drive unit

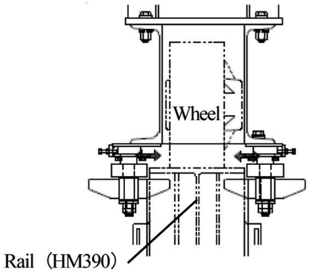
5.2 Operation method of the movable roof

As shown in **Fig. 14**, the operation method of the roof involves providing wheels at four corners of each roof block to move the roof block on the rail (H-beams). One motor each is installed on the left and right of a roof block and the moving speed is adjusted through inverter control. In order to verify the driving properties of this operation method, an offline test on the ground was performed. The operation speed, meandering properties, motor load, and operation properties when driving/stopping were checked.

During the offline test, the roof blocks ran without any difficulty on the rail including locations with the misalignment of H-beams and with joint clearance. However, since the motor power was determined as the minimum necessary level, the roof blocks were disabled from running in a position with dust that constituted a differ-



(a) Application of device



(b) Cross-section of rail

Fig. 15 Assisting device to drive

ence in height of about 10 mm on the rail. In order to address this situation, scrapers were provided at the front and rear of the wheels for removing deposits on the rail to make the surface of the rail even enough for roof blocks to run. In addition, as assisting driving devices (**Fig. 15**), side rollers to prevent wheels from derailing and meandering, an anti-lifter to prevent the roof from floating, buffers to reduce impact when colliding with each other or other objects, and limit switches to decelerate or stop when sensing contact with adjacent roof blocks or stoppers were provided for smooth movement of each block. For the operation properties of each drive unit, another test was conducted in which roof blocks ran up to the predetermined position with no shock generated at the start and stop.

5.3 Use of coke oven facilities

Distortion and stress were examined using the structural model using BS and PH, which constitute part of the coke oven facilities, as components of a temporary building. An image of the use of BS and PH as the components of the building is shown in **Fig. 16**. In order to prevent BS from falling, frames that form the shape of a gate (hereinafter referred to as the "upper frames") are provided above BS, and columns to support the outer wall are installed above or in the vicinity of PH. The upper end of each column is connected to an upper frame (hereinafter referred to as the "outside frame"). Multiple BSs are provided in the longitudinal direction. Horizontal connection elements, which allow these BSs to collectively work as one member of the temporary building, are provided. In addition, in order to distribute the horizontal force to PH, the brace location and joint details are changed to improve the horizontal rigidity. In this manner, the BS group and PH were used to establish the structural model shown in **Fig. 17**. Structural analysis using this structural model was conducted, in which it was confirmed that stress and distortion of BS, PH, upper frames and outside frames satisfied the requirement performance. As a result, the structural safety was verified.

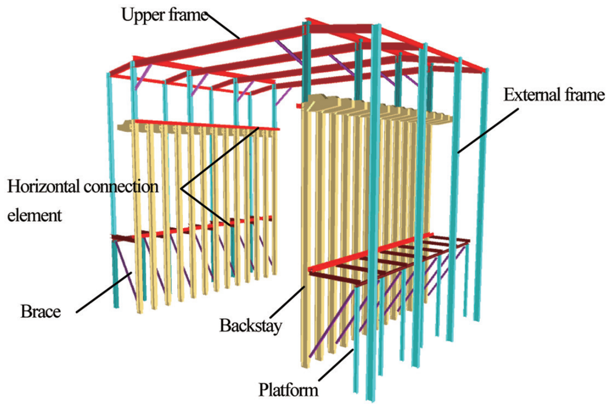


Fig. 16 Structural image

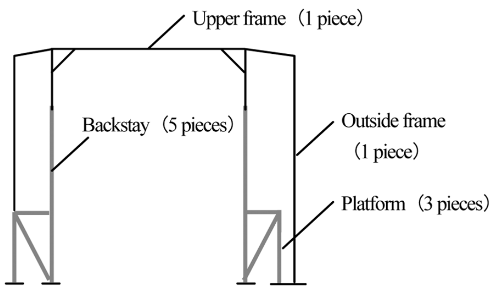


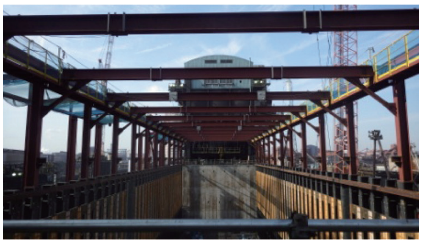
Fig. 17 Structural model

6. Confirmation of the Effect with an Actual Unit

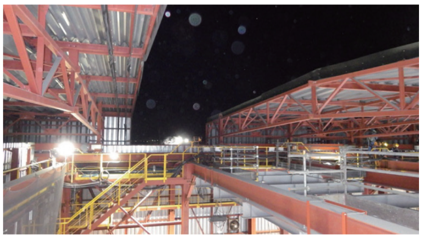
The temporary building for coke ovens developed as a result of these initiatives was applied to the No. 4 coke oven at Kimitsu Works (completed in September, 2015) and the effect is described as follows.

Photographs taken when building and disassembling the temporary building according to the method described in this report are shown in **Fig. 18**. For the waterproof performance of the movable roof, based on the results of the preliminary tests for wind resistance and water resistance, 5mm-thick rubber sheets were used between the roof blocks and those 10mm-thick were used for the eaves. This resulted in sufficient waterproof performance, causing no water entry from between the roof blocks or eaves.

Using the operation method of the movable roof described in this report, performance almost equivalent to the preliminary driving test was shown for the driving speed, meandering properties, and motor load. It was confirmed that the roof blocks could be moved to the predetermined position with no impact caused by the start or stop. In addition, as a result of the use of part of the coke oven facilities as components of the building, the amount of steel was reduced by 150 tons (approx. 30%) and the temporary building construction period was shortened by 30 days (approx. 30%). Although the machine work for constructing the movable roof caused the construction period to be slightly extended, the total reduction of 18 days for the building and machine work was achieved, showing a sufficient effect for the overall construction period even when the movable roof was constructed. For the removal of the temporary building, the roof and wall divided into large blocks allowed for disassembly that required no scaffolding, providing a reduction of about 10 days compared to conventional methods.


(a) Utilization of coke oven equipment


(b) Construction of movable roof


(c) Opening of movable roof


(d) Completion of temporary building


(e) Demolition of temporary building


(f) Cutting of movable roof

Fig. 18 Construction example

7. Conclusion

This report described a next generation temporary building developed through the reconsideration of the function required for a temporary building for coke oven construction to ultimately reduce the space the building occupies. This temporary building has already been constructed at Kimitsu Works and has largely contributed to improvement in the construction cost and work period. In addition, we will not only work on the expansion of the use of this method for coke ovens to be constructed going forward, but will also pursue a different perspective that allows us to produce a new steelmaking facility.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