DESIGN AND CONSTRUCTION OF YODOKO SAKURA STADIUM
- Substantial PCa conversion and Japan's first application of brightly colored concrete for achieving a decarbonized society -

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SUMMARY

YODOKO SAKURA Stadium is the home stadium of Cerezo OSAKA team, which plays in the J1 professional soccer league in Japan. With the aim of making it a "world-class stadium," the new stadium has a capacity of approximately 25,000 seats under the slogan of "a stadium that promotes the development of a nurturing club”. This report describes the design and construction course, focusing on the precast construction, with a view on the phased renovation in the future. In addition, new technologies concerning new environmentally friendly concrete and colored concrete using cements with high blast furnace slag content are reported.

***Keywords**: Stadium, on-site precast, high blast furnace slag cement, colored concrete*

1. INTRODUCTION

The World Cup will be held in Qatar this year, and many stadiums were built in Japan when the World Cup was held in 2002.In recent years, many new stadiums have been completed in Japan, including Suita Stadium, Kyoto Stadium, and National Stadium, and construction is currently underway in Nagasaki City and Hiroshima City, indicating that many stadiums have been built since the 2002 World Cup.
In Japan, especially in the construction of large (large seating capacity) stadiums, rebuilding due to aging and other factors.On the other hand, small to medium-sized stadiums have been renovated to increase capacity or to install roofs, but there are very few stadiums that have been renovated over many years and are being renovated with future plans in mind.

This project involves the renovation of Nagai Stadium (former name of Yodoko Sakura Stadium), the home stadium of Cerezo Osaka, team which plays in the J1 Japanese professional soccer league. The project owner has gradually made several small-scale renovations in the past, in accordance with the growth of the club. The current renovation is planned to expand the stadium from its existing capacity of approximately 18,000 seats to a 25,000 seats. In the future, the owner aims to attain 40,000-seats.
In order to realize a decarbonized society, the project owner, designer, and constructor, after long debates and discussions, developed an optimal plan for the project and achieved a high site PCa conversion ratio of approximately 86%. In addition, a concrete of bright pink color, the color of Cerezo Osaka team, was applied for the first time in Japan in the structure at the pitch entrance reserved for the players, creating a concrete building that will be loved by the club members and its supporters as well as the local community. Photo 1 shows the exterior of the building, and Photo 2 shows the colored concrete used for the mentioned entrance.

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Photo-1　view of the building from the pitch

Photo-2　Colored concrete used for the pitch entrance

Building Outline

Number of floor	: (Main Stand) 5 floors above ground , Building height : 32.26 m
Type of Structure	: (Main Stand) RC, (roof) Steel,(South Stand) RC Construction, (North Stand) Steel
Foundation structure	: (Main stand) Pile foundation and spread foundation (South stand) spread foundation, (North stand) spread foundation
Building area	: 7,869.16 m^2 , Floor space : 17,295.86 m^2 , Site area : 38,494.71 m^2
Location	: 410-5 Nagai Koen, Higashisumiyoshi-ku, Osaka City and other 209
Architects	: (Structure and equipment) Takenaka Corporation, Osaka First-Class Architect Office (Design) IAO Takeda Architects Associates
Constructor	: Takenaka Corporation Osaka Office

2. Architectural plan outline

2.1. Design Concept

The layout of the stands is shown in Photo 3. This project’s plan was to reconstruct some of the existing stands and renovate some others in phases similarly to some renovations carried out on many soccer stadiums in Europe. The project owner's basic concepts for this project were:

- Achievement of phased renovation in accordance with the growth of the club.
- Inducing the most intimate feeling in Japan!
- Providing an urban stadium for the community
- Nurture together with everyone

With the above concepts in mind, and after holding various meetings with the project owner, the following four design concepts were adopted for this project.

1) Integration with the existing stand

The plan was to maximize the use of the existing building in anticipation of future renovation and reconstruction.

2) Spectator seating focused on spectatorship

The upper level of the two-tiered spectator seating was brought up above the lower level to allow the spectators. The distance between the front row of spectator seats and the pitch was set to 5.8m, and the roof coverage was set to approximately 70%, in order to improve the spectator environment.

3) Urban stadium for the community

The stadium was planned as a complex facility that included a restaurant, wedding hall, rental office, culture school, etc., so that local residents can use it on days other than game days. In addition, road on the west side of the main stadium is also planned to be integrated with the urban planning road network to promote regional revitalization.

4) building intended as a symbol of the community.

Whereas the main body of the stands has a massive and heavy presence created by the concrete structure, the large roof, with only the lower stringers painted white, gives the impression of lightness.

The design is made light and comfortable, in order not to spoil the view of the surrounding residential area.

Photo-3　Layout of stands (view from the south side)

2.2.　Building Layout Plan

Figure 1 and Figure 2 show the layout of the building before and after renovation. The project involves the following three main tasks.

1) Demolition of the old west stand and construction of a new main stand
2) Extension of the North Stand
3) Extension of the South Stand

The site is located in the northwestern part of Nagai Park in Osaka City, with an urban planning road (the road project had been decided at the time of the start of stadium construction), near the elevated JR Hanwa Line to the west, and neighboring a residential area to the north.

Since the existing stands behind the north and south goals were to be renovated, the existing layout was left as it was, and extensions were built in the remaining space behind the existing stands. As the north stand is located in close proximity to a residential area, it is enclosed on its three sides by a wall integrated with the roof to minimize noise.In consideration of the growing environment of the natural turf on the pitch and after consultation with the owner, the south stand behind the goal was left unroofed to ensure ventilation between the stands and to secure sunlight.

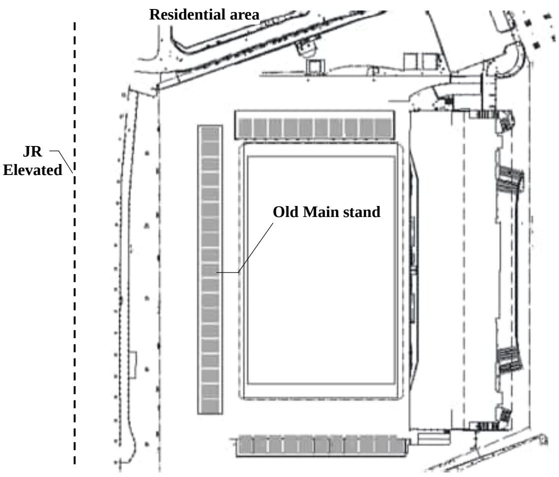

Figure-1　Layout (before renovation)

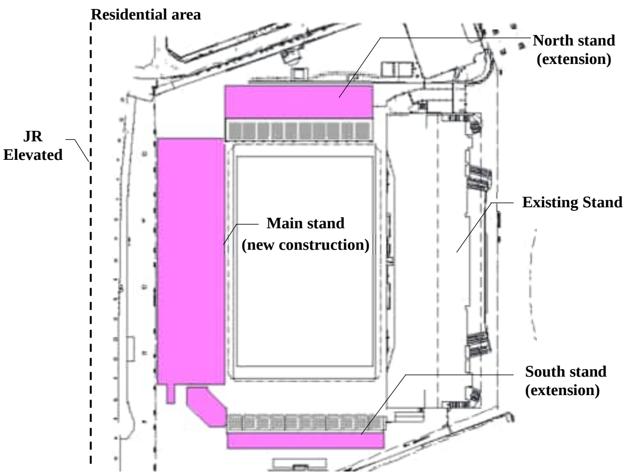

Figure-2　Layout (after renovation)

2.3. Main Stand Architectural Plan

The plans of all floors of the main stand are shown in Figure 3 through Figure 7, and the section view of the structure is shown in Figure 8. The second and fourth floors are concourses with access to the spectator seating area, and the VIP rooms are located on the third floor.

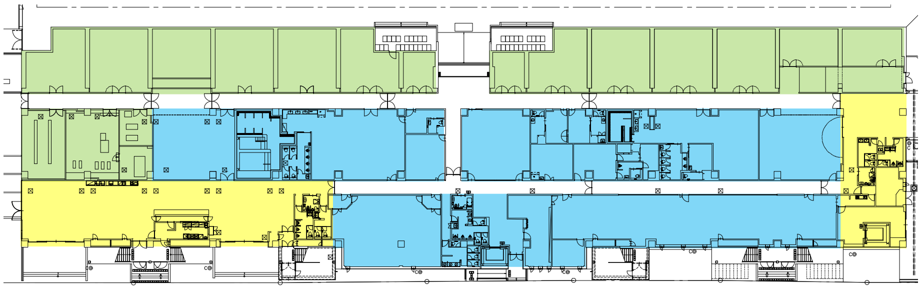

Figure-3 1st floor of the Main Stand

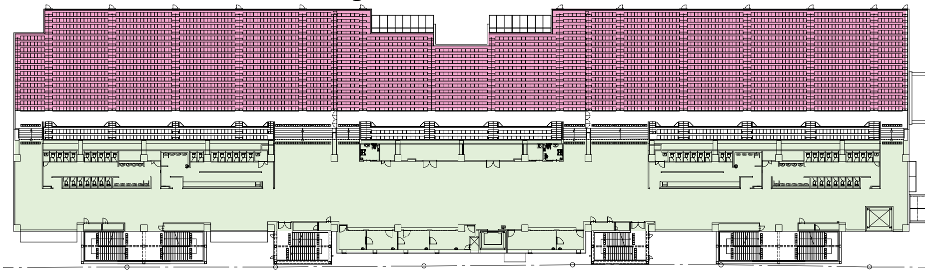

Figure-4 2nd floor of the Main Stand

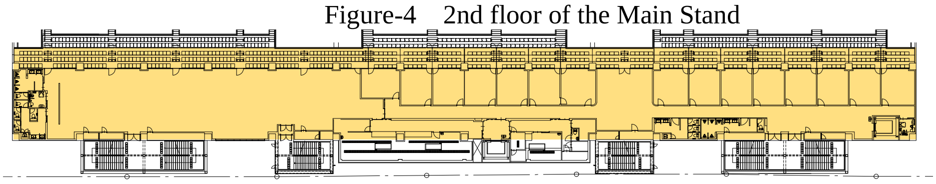

Figure-5 Main Stand 3rd Floor

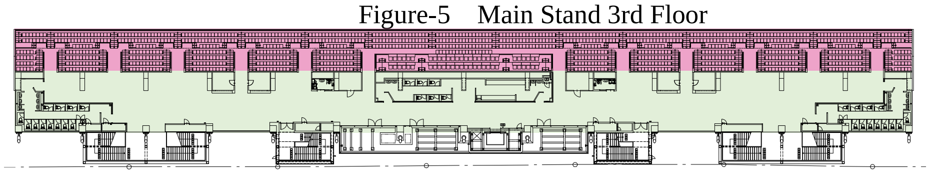

Figure-6 Main Stand 4th Floor

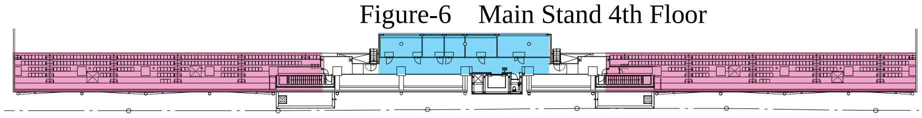

Figure-7 Main Stand 5th Floor

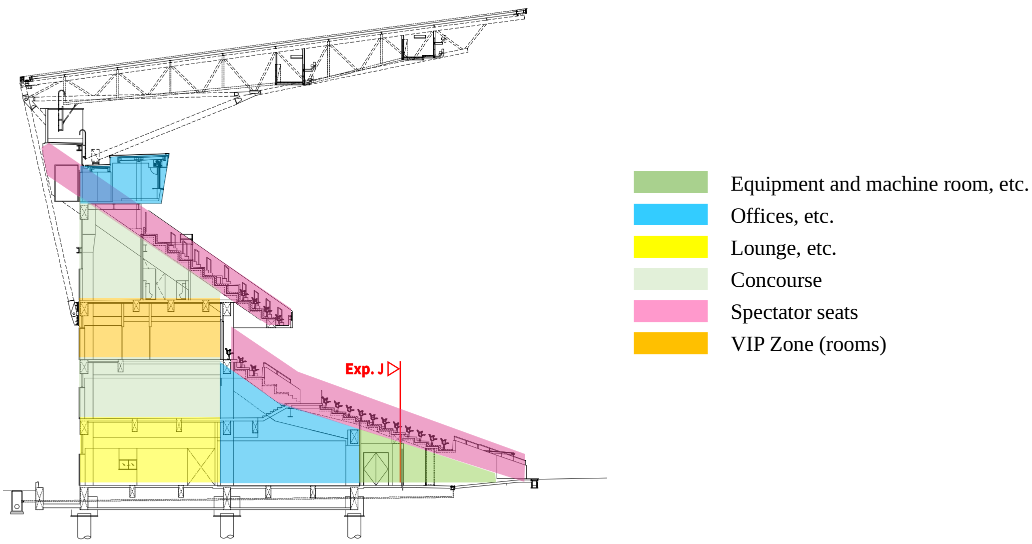

Figure-8 Section view of Main Stand

2.4. Architectural Plans for North and South stands

Sections of the north and South stands are shown in Figure 9 and Figure 10.

For both cases, whereas the existing stands are to be preserved, a new stand is to be added behind each of the existing stands.

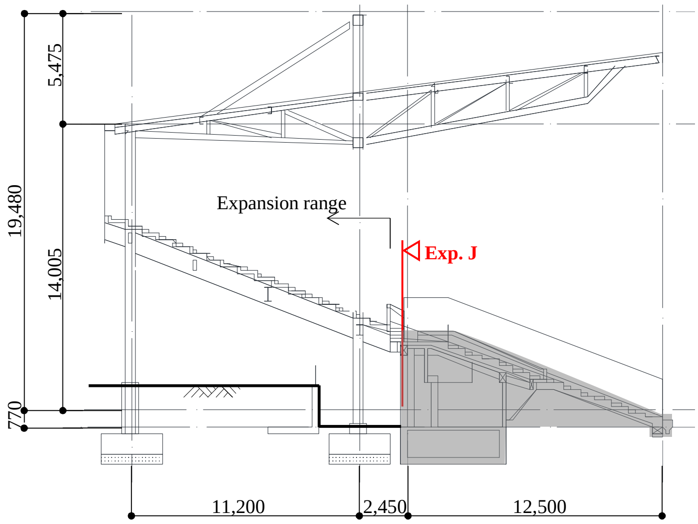

Figure-9 Section of the north stand

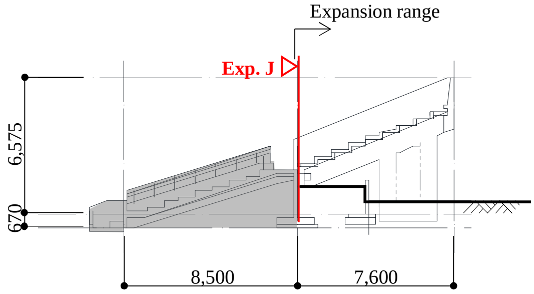

Figure-10 Section of the south stand

3. Structural frame design

This chapter describes in detail the efforts to decarbonize the building (using Site PCa and ECM cement) and the challenge of applying colorful concrete for the first time in Japan.

3.1. Main stand structural frame design

Figure 11 shows an elevation section for the short side of the main stand. The main stand was constructed of reinforced concrete in order to suppress vibrations caused by a large number of walkers during games and jumpers during cheering. The structural system was made of a rigid-frame structure in the east-west direction (short side of the building) and a braced frame structure in the north-south direction (long side of the building). The nominal strength of concrete was 45 N/mm^2 for columns and girders, 36 N/mm^2 for foundation elements, and 24 N/mm^2 for beams and slabs.For the roof, one-direction cantilever trusses were used , as the roof can be extended considering the same design for future additions. The roof trusses are installed above the projecting columns, so that the roof trusses do not block the view of spectators toward the pitch, which is particularly important in the structural planning of any soccer stadium.

The following two points were particularly considered in the structural planning of the main stand.The first point was the improvement of the quality of concrete for the entire stand and the safety during construction. In a soccer stadium, ideally, all spectators should be able to see the pitch from all seats, which consequently limits the layout and tilt angles of the spectator stands. Therefore, when beams are installed to match the inclination angle, as shown specifically in Figure 11, the number of diagonal beams increases, and the reinforcement and formwork at the column-beam joints is often more complicated than in common buildings. Since there are many restrictions in terms of construction period, safety, and quality in performing the complicated reinforcement arrangement of the column and beam joints on-site, the authors considered actively promoting the use of PCa construction for higher quality elements.

Concerning the second point, Cerezo Osaka home stadium is the first stadium in Japan to use environmentally friendly and colored concrete. For soccer supporters and local residents, there is a very high awareness that their home stadium is theirs. Generally, team colors are expressed in the seats, but the project concept of "Inducing the most intimate feeling in Japan!" as well as the strong desire of the project owner to be labeled with "the first structure to be applied in Japan" became clear at the design stage, the authors aimed to improve the attaction of the stadium and make it a stadium that will be loved by supporters and local residents for a long time to come. Since painting the stadium would not achieve the owner's request, the authors decided to use ECM colored concrete as the material to be used for the entrance, considering its coloring properties.

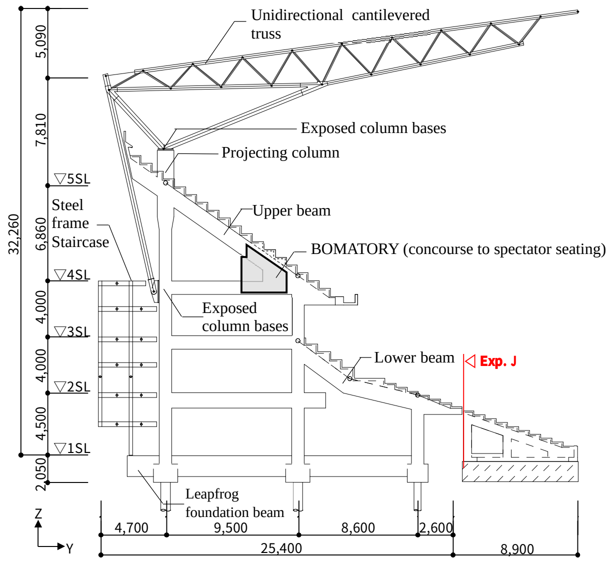

Figure-11 Frame elevation for short side of main stand

Pattern diagram showing the features of the frame design of the main stand is shown in Figure 12. The diagram presents the tiered beams of the stands as horizontal members for clarity.

In the structural planning of a typical stadium design, a structural challenge resulting from the section shape of a stadium with many diagonal beams is that horizontal forces are concentrated on the very short columns at the top of the stands, as shown in the left figure in Figure 13. In this project, to avoid this problem, an Expansion Joint (hereinafter referred to as "Exp. J") was installed in the short column to make the rigidity of the entire stand uniform, as shown in the right figure of Figure 12.

In addition, since the weight of the front part of the stand is relatively light, a spread foundation was used and the structure was designed with RC walls to achieve a clear structural plan shear forces on the columns were made uniformly.

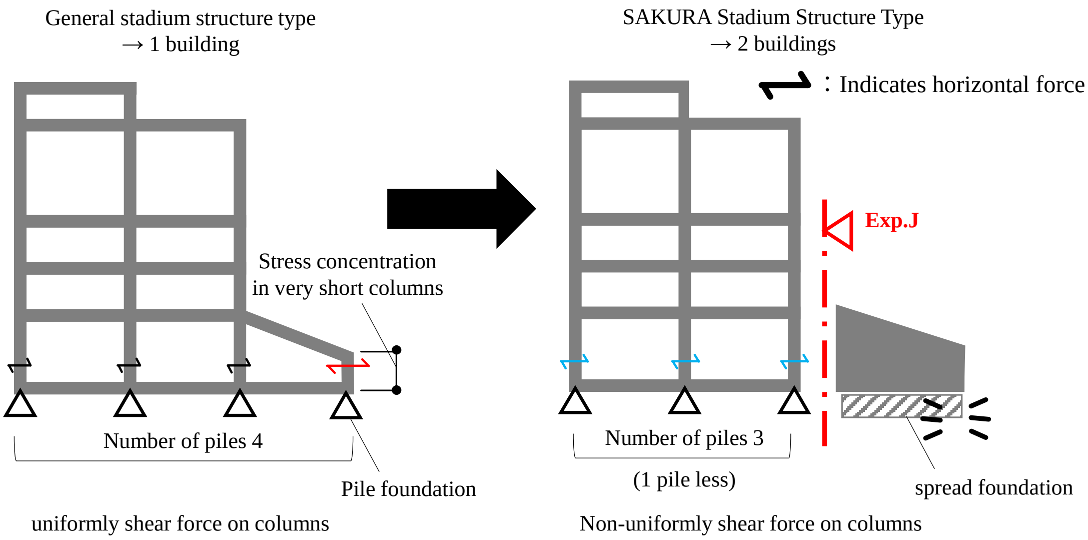

Figure-12 Features of the frame structure (Pattern diagram)

3.2. Structural frame design of the stand behind the south goal

As shown in Figure10, the South Goal Rear Stand is a building with only spectator seats, and like the North Goal Rear Stand, it is planned to increase the number of seats to the rear of the existing stands. After discussions with the project owner, the authors decided not to erect a roof in anticipation of a future expansion, and because the stand expansion was relatively small, the authors decided to use an RC structure with a spread foundation, which is easy to connect with the PCa tiered floor slab.

In addition, the structural plan for the stand behind the south goal aimed the use of ECM Concrete for almost all the elements to contribute to decarbonization, as described in detail in Chapter 5.

4. PCa conversion of foundation and frame

4.1. Overview of PCa conversion

Figures 13 show the PCa member allocation of the main stand. The general approach to improve the efficiency of PCa conversion is to unify the section as much as possible to increase the number of times the formwork can be diverted for fabrication in the factory, and to maximize the transportable range. This project, like most stadiums, has a relatively large structural section and high weight of PCa members, making it unsuitable for factory fabrication. Fortunately, as the layout plan of this project allowed the entire pitch to be used as a construction yard, it was possible to shorten the construction period by making the members as large as possible and reducing the number of pieces. On the other hand, it is known that the precision of wooden formwork fabrication on site is inferior to that of the factory. Therefore, in order to improve the accuracy of the formwork, the formwork material was made of thicker elements than usual, and the number of diversions was increased, thereby reducing the amount of CO2 emissions.

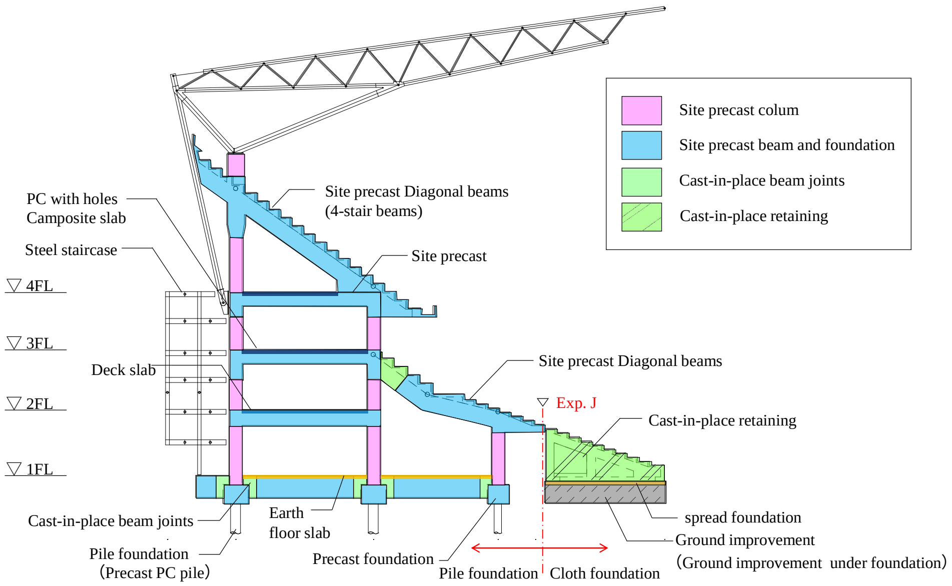

Figure-13 PCa member allocation diagram (Section)

4.2. PCa construction of foundation

The foundation members are the first PCa members to be used at the start of construction. Therefore, the design and construction plan were developed through early collaboration between the designer and the contractor, where the design was carried out in parallel with the construction seven months drawing-based delivery study seven months prior to the start of construction, design and construction drawings were prepared in parallel. As discussed in section 3.1, the structural plan for the Exp. J was designed to omit Pile head reinforcing bars by making the structure such that all foundations would not be subjected to pull-out forces in the event of an earthquake.This made it easy to convert the foundations to PCa elements. In addition, since the foundation PCa elements can be moved horizontally to some extent without pile-head reinforcement bars, the column members can be converted to PCa elements directly above the foundation and the position of the foundation PCa elements can be adjusted, making it possible to adjust and secure the construction accuracy of the position of the column main reinforcement bars. Figure 13 shows a detailed drawing of the foundation PCa element reinforcement. As shown in Figure 14, the foundation beams were also made of PCa elements, minimizing the amount of concrete placement on site. Photo 4 and Photo 5 show the construction of the foundation.

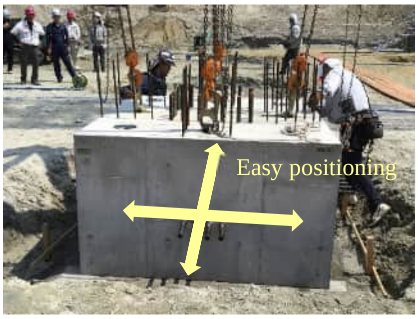

Photo-4 Installation of PCa foundation

Photo-5 Installation of PCa column

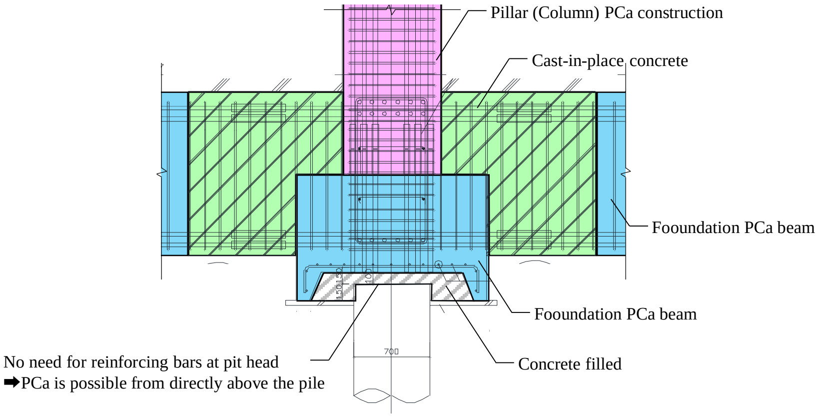

Figure-14 Detailed drawing of foundation PCa element reinforcement

4.3. PCa Construction of above-ground frame

The above-ground frame members were all planned as site PCa elements, since there was room in the process. As shown in Figure 13, two types of PCa elements were planned for each member: (1) PCa construction integrated up to the column and beam joints, and (2) orthogonal direction beams. By integrally fabricating the column-beam joints, it was possible to construct the frame work as PCa members of high quality for the parts where the delivery was complicated.

The PCa members were fabricated on site as shown in Photo-6, and large-size heavy equipment could be used to lift the roof members, which was unique to the stadium. Furthermore, by dividing each stand into separate buildings, it was possible to design the section of each span with the same section, which greatly improved the number of times the formwork could be diverted during the PCa member fabrication process. Also, as shown in Photo-7, the topmost small beam integrated with the handrail wall was fabricated as a PCa beam with walls.The maximum weight of the PCa members was approximately 40 tons for the upper beam on the fourth floor, and the maximum length of up to 15 m was fabricated as a single unit.

Again, as shown in Photo-8 and Photo-9, by promoting the use of PCa construction as much as possible, including the upper beams and the PCa of passageway (the part that serves as a passageway from the concourse to the audience seats), the authors achieved a PCa conversion rate of 86% (the amount of PCa-concrete to the total concrete volume) in the main structural parts, which contributed to the realization of more decarbonization and a more sustainable society.

Photo-6 PCa rebar built-up status at 3rd floor Girder site

Photo-7 PCa beam with wall (lower level)

Photo-8 Upper beam (Installation status)

Photo-9 PCa of passageway PCa (demolding status)
(aisle from concourse to spectator seating)

5. Application of low-carbon blast furnace slag-containing concrete (ECM Concrete) to the above-ground frame
ECM Concrete is a low-carbon concrete with high content of blast furnace slag, a byproduct of steel production, and the addition of gypsum to improve cracking resistance.ECM cement*1), As the South Goal Rear Stand was planned with 500 mm thick walls and 1,000 mm thick mat slabs, there were concerns about thermal cracking and drying shrinkage of the concrete due to such large sections. ECM Concrete was an appropriate solution as it is less susceptible to cracking due to drying shrinkage than ordinary Portland cement. Furthermore, from a decarbonization perspective, the use of ECM Concrete enabled a reduction of approximately 50 tons of CO2 emissions in the South stand. Photo-10 shows a panoramic view of the stand behind the south goal, and Photo-11 and Photo-12 show, respectively, the fresh ECM concrete test and construction conditions.

Photo-10 South goal backstage stand (general view)


Photo-11 ECM Concrete test status


Photo-12 ECM Concrete construction status

*1) ECM (Energy/CO_2 Minimum) cement: Cement made mainly from blast furnace slag, a byproduct of steel production, that requires no calcination, reduces energy consumption and CO2 emissions in cement production by more than 60% compared to conventional cement. The cement was developed by a joint R&D team of seven companies and one university under the "Strategic Development of Technology for Energy Use Rationalization" (FY2008-2010) and the "Development Project of Innovative Technology Agency for Energy Conservation" (FY2011-2013) of the New Energy and Industrial Technology Development Organization (NEDO).

6. ECM Concrete with high coloring performance
Colored concrete is a concrete that is colored by mixing pigment powder into the concrete itself. The problem with coloring concrete is that the color of the cement itself (gray) reduces the pigment's colorability. White cement can be used as a concrete cement, but legal restrictions and economic problems have made its adoption difficult. For the above reasons, colored concrete that has been employed so far was relatively dark, such as black concrete, and various difficulties have been emcountered to realize bright colors such as pink and yellow.
On the other hand, as this stadium is the home stadium of Cerezo Osaka team, and in order to provide the stadium with unique identity, the authors planned and challenged to realize the employer's request by expressing the pink color, the team’s color, in the stadium itself with concrete.
To solve the coloration problem, the authors developed "ECM Color Concrete" with high coloration by using ECM Cement, which contains white blast furnace slag fine powder and has high coloration of pigment added. This cement has already obtained technical certification for actual applications and has few legal restrictions. To confirm the coloring properties of this colored concrete, a total of three test runs were conducted, in which the concrete had a bright pink color.
The mix testing and placing of ECM colored concrete are shown in Photo-13 to Photo-15, and Photo-16 shows the photos taken upon completion of the field test work. ECM colored concrete was applied for the first time in Japan, and the application of this highly original technology added high technical value to the stadium and increased its attractiveness. The stadium will be loved by supporters and local residents for a long time. The actual entrance was widely spread by TV broadcasts and most of the media coverages.

(a) Research & Development Institute

(b) Field test construction

Photo-13 ECM colored concrete mixing test

(Left: ECM Color Concrete, Center: ECM Concrete, Right: Ordinary Portland Cement)

Photo-14
ECM Color Concrete compressive strength test specimen

Photo-15
Placement of colored concrete on site

Photo-16 ECM colored concrete wall at completion

7. Summary

The stadium building with a complex section shape was realized with high quality by adopting large site PCa members and actively using PCa construction, and by applying colored concrete using ECM Concrete. A high PCa conversion ratio of about 86% was achieved, contributing to the realization of a decarbonized society, the most important social issue in recent years. In addition, the authors succeeded in realizing pink (relatively light color) colored concrete, the first application in Japan, and demonstrated new possibilities for concrete structures. In addition, the authors are widely disseminating and educating the public about these technical details through the Journal of the Japan Concrete Institute, press releases, and presentations at overseas academic conferences.