Urban-Ring Method™/Urban-Wall™ Method — Urban Caisson Method Developed in Urban Areas —

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Abstract:

Outline and examples of construction of urban press-fitted caisson, "Urban-Ring Method™", are introduced. It was developed for severe construction environment in urban areas in late 1990s. In addition, recently developed "Urban-Wall™ method" is described in detail. This method corresponds to the large cross section larger than 30 m in diameter utilizing the features of the Urban-Ring Method. Composite structure of the main body, fitting bending performance test, assembling test at the factory and plans of test construction at the site are introduced.

1. Introduction

The Urban-Ring Method™[1,2] is an urban caisson method that was named and launched together with the Urban-Ring™ material, simultaneously with the start of Society for the research of Urban-Ring method in November 1996. As the name "Urban" indicates, it is used as a temporary earth-retaining method for vertical shafts and foundation construction, mainly in urban areas and their environs.

This method enables construction under a variety of difficult conditions, including neighboring construction, construction on narrow space construction with overhead height restrictions or difficult groundwater conditions, and construction under roads or with short construction period requirements.

The Urban-Ring method was developed from the viewpoints of both materials and execution based on the fundamental concept of constructing underground structures in the vertical direction by using rings with a segmented structure, which are fabricated in the factory The cumulative record of construction has now reached installation of 360 units and approximately 400 000 m^3 of excavated soil since the start sales in 1991 of the steel segment press-fitting construction method, which was the predecessor the Urban-Ring method.

On the other hand, with further advances in underground construction of structures, technologies for rapid construction of large diameter and large depth vertical shafts have been demanded in recent years. To meet these requirements, JFE Metal Products and JFE Steel developed the Urban-Wall™ method[3,4] for large cross section shafts with diameters exceeding 15 m, which could not be constructed until now with the Urban-Ring method, while continuing to take advantage of the features of construction on narrow ground and rapid construction of the Urban-Ring method. This paper presents an outline of the Urban-Ring method, and also reports on various tests that were conducted in the development of the Urban-Wall method.

2. Outline of Urban-Ring Method™

In the Urban-Ring method, as shown in **Fig. 1**, Urban-Ring pieces (in case of a steel piece structure), which have been fabricated in the factory are assembled in a circular or elliptical shape. The rings are stacked in the vertical direction, and the space inside the rings is excavated using mainly a clamshell or other bucket type excavator (**Fig. 2**). The ring structure is then press-fitted into the ground to the required depth by using the reaction force provided by installation ground anchors.

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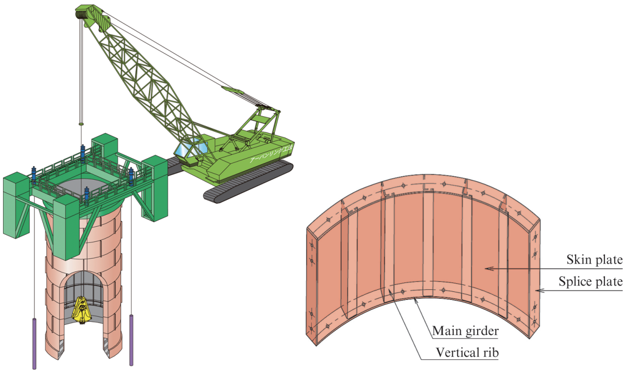

Fig. 1 Steel piece structure

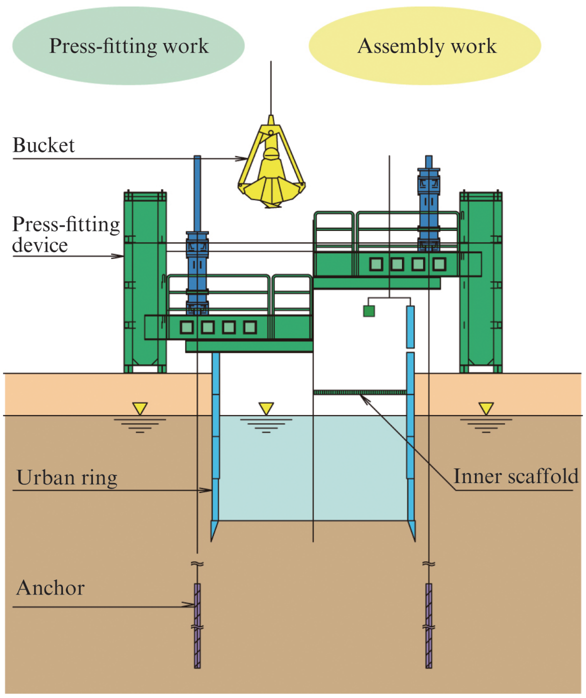

Fig. 2 Drilling Urban-Ring Method™

Because factory-made products are used in the Urban-Ring body, the Urban-Ring method has high dimensional accuracy. Therefore, the amount of friction cut (overbreak, i.e., over-excavation) of the cutting edge can be reduced to half or less of that of site-fabricated caissons, which have large tolerances, and the effect of Urban-Ring construction on the surrounding ground is slight. Construction speed is overwhelmingly faster than in caisson construction, as it is not necessary to cure the caisson body at the site, and environmental loads associated with construction can be reduced. Moreover, Urban-Ring is also a safety-conscious construction method, since the assembly work is carried out on the ground and the height of the rings is small, at around 1 m. As an additional advantage, construction is possible in a small space, even at sites where the plane-area of the construction yard is limited, because the press-fitting equipment itself is compact

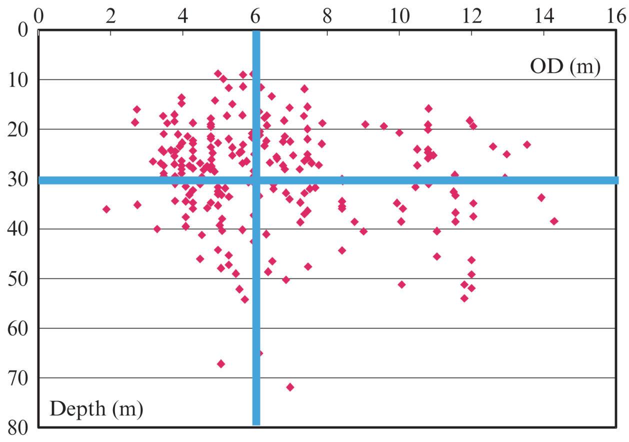

Fig. 3 Construction record of urban-ring

and the Urban-Ring pieces are delivered from the factory in line with the site construction schedule.

Because the Urban-Ring method is based on underwater excavation, heaving and boiling are not issues. Its range of applications has also been expanded by use in combination with precedent drilling as a complementary method, for example, in case of hard ground or other problems. Moreover, the lubricant injection method is effective not only for reducing pressing-fitting resistance, but also for stabilizing the surrounding ground.

The advantages of this method in vertical shaft construction, which accounts for the majority of applications, can be summarized as follows.

(1) High degree of freedom in design and construction
(2) Small load on surrounding environment
(3) High construction accuracy
(4) Quick construction

3. Construction Record of Urban-Ring Method™

Taking advantage of the features of "construction on narrow ground" and "short construction period," the Urban-Ring method has accumulated a construction record in various applications and under various conditions. **Figure 3** shows the distribution of the construction record by outer diameter and construction depth. The average outer diameter and depth in this record are 6 m and 30 m, respectively. In recent years, there has been a trend toward large depth and larger outer diameter due to increasing application of the Urban-Ring method to start/arrival shafts for shield tunnels.

Examples of the applications of Urban-Ring construction also cover a diverse range, including vertical shafts, manholes, bridge substructure casings, bridge pier reinforcement, wells, and underground parking facilities, among others. A steel Urban-Ring structure

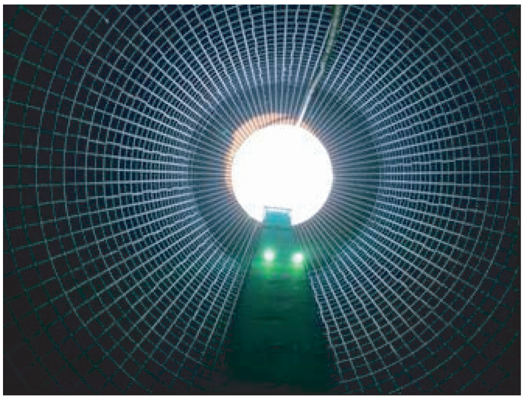

Photo 1　Steel urban-ring

Photo 2　Concrete urban-ring

Photo 3　Construction site

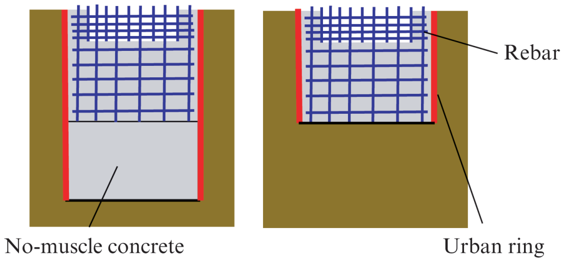

Fig. 4　Comparison of bottom plate

(**Photo 1**) or a concrete structure (**Photo 2**) is used, depending on the application.

Steel is used mainly in small lot or temporary structures, whereas concrete is used in permanent structures and in structures produced in large numbers in the same size lot.

The scene at a general construction site is shown in **Photo 3**. As can be seen in this photograph, construction is possible if a site with an area about 3 times that of the shaft being constructed can be secured.

One example of the use of the Urban-Ring method in a bridge pier foundation is the foundation works of the Nishisemba Junction connecting the Route No. 16 Osaka Port Line and the Route 1 Loop Line of the Hanshin Expressway[5,6]. Although use of the open caisson method was originally planned for this project, overhead space under the existing overpass bridges was limited, and since it was also necessary to minimize occupancy of these main arterial highways for construction work, shortening of the occupancy period was required. Because the Urban-Ring method enables construction on narrow ground and a short construction period, shafts constructed by the Urban-Ring method were used as temporary earth retaining walls, and caisson foundations were constructed inside the shafts. Adoption of this construction method shortened the construction period by approximately 40%.

In addition, in the normal Urban-Ring construction method, a caisson foundation is constructed inside the shaft by the method shown on the left in **Fig. 4** so as to withstand uplift pressure. However, in the construction at the Nishisemba Junction, that method was rationalized based on repeated study of the structure itself and innovations in the construction method so that the bottom plate of the Urban-Ring method could be regarded as the body structure of the caisson foundation, as shown on the right in Fig. 4.

Next, the foundation construction for the Metropolitan Expressway (Shutoko) Yokohama-Kohoku Junction will be introduced[7]. At this worksite, the geology from the ground surface to the bearing stratum line is mostly alluvial cohesive soil (clayey soil) with N-values of 0 to 1, with an underlying mudrock formation having an N-value of 50 or more. Thus, this was a difficult site, as it is necessary to secure lateral subgrade reaction force in the bearing stratum, and the embedment length of the cutting edge in the bearing stratum was more than 15 m. Construction by the pneumatic caisson method was originally planned, but excessive time would have been required to sink the caisson accurately in the extremely weak ground with an N-value of substantially zero. Therefore, the Urban-Ring method was adopted, as press-fitting can be controlled by the sinking system. There was also concern that it would become impossible to press-fit the cutting edge at the tip of the Urban-Ring structure into the hard mudrock formation. Although sand replacement by precedent drilling was studied, with the conventional

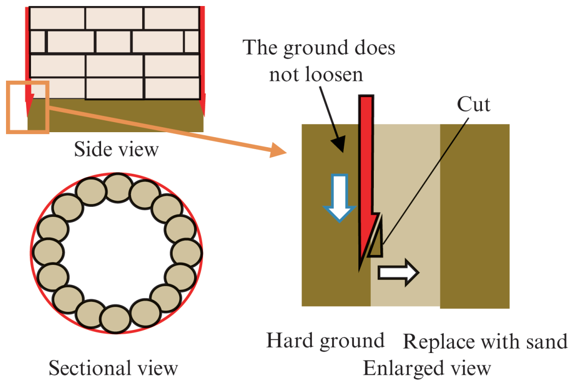

Fig. 5 Mechanism of preceding drilling and cutting edge

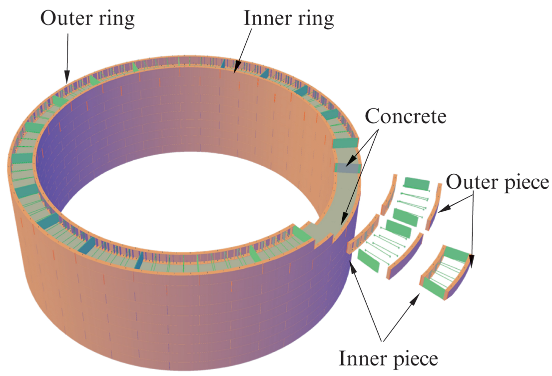

Fig. 6 Outline of ring

precedent drilling method, the subgrade reaction of the side surface cannot be expected because the ground surrounding the foundation is loosened. Therefore, as an innovation that made it possible to press-fit the rings without loosening the ground outside the structure, the range of sand replacement was limited to the inner side of the ring, as illustrated in **Fig. 5**.

4. Outline of Urban-Wall™ Method

4.1 Ring Structure and Piece Structure

In the Urban-Wall method, a double-walled steel shell structure comprising an inner ring and an outer ring, as illustrated in **Fig. 6**, is used to support a large cross section with a diameter of approximately 30 to 50 m. In constructing the body of this composite structure, normal-size steel pieces fabricated in the shop are assembled in one-ring units at the site, the inner and outer pieces are connected with splicing materials, and concrete is poured in the central part between the pieces.

As can be understood from **Fig. 7**, small steel pieces fabricated in the shop are transformed into large pieces with a composite structure at the site. The large composite-structure pieces are assembled by using splicing materials and segment joints (joints between the pieces, joints between the rings) installed at the edges or top of the small steel pieces. The composite-structure segment pieces with these segment joints make it possible to construct a flexible structure, thereby improving earthquake-resistance as a vertical shaft.

As shown in **Photo 4**, the joints between pieces have a structure in which the joint of a flat-section steel sheet pile (J-Flat Pile™) manufactured by JFE Steel is connected directly to the skin plate. Since the joints of J-Flat Pile have high yield strength and a shape that enables insertion from the top, it is possible to apply multi-segment boltless joints, contributing to fast construction during assembly.

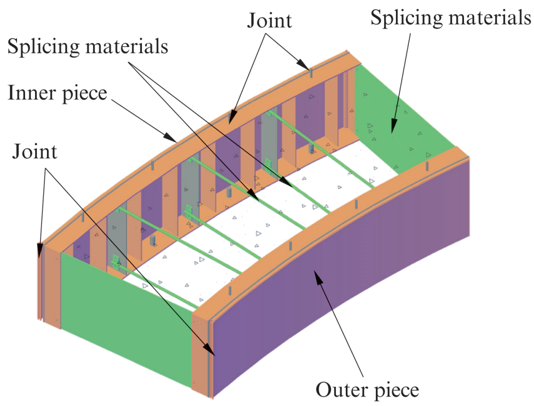

Fig. 7 Piece structure

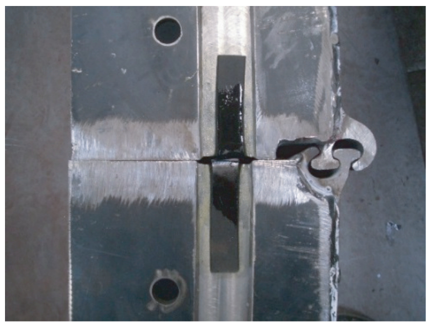

Photo 4 Joint structure

4.2 Cutting Edge Structure

The cutting edge of the conventional open caisson generates hoop tension (tension in circumferential direction) due to the wedge shape between the side wall and the bottom slab.

In the cutting edge of the Urban-Wall method, a cutting edge shape with an acute angle is obtained by changing the thickness of the side wall in a step-by-step shape, as illustrated in **Fig. 8**. The earth and sand at the cutting edge is excavated following this edge shape, and the soil can then be removed with a clamshell.

Upon completion, the hoop tension caused by

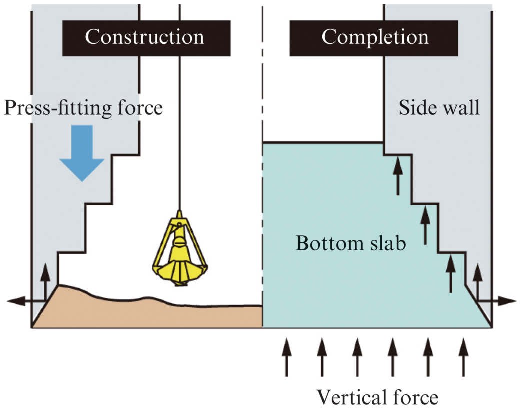

Fig. 8 Cutting edge structure

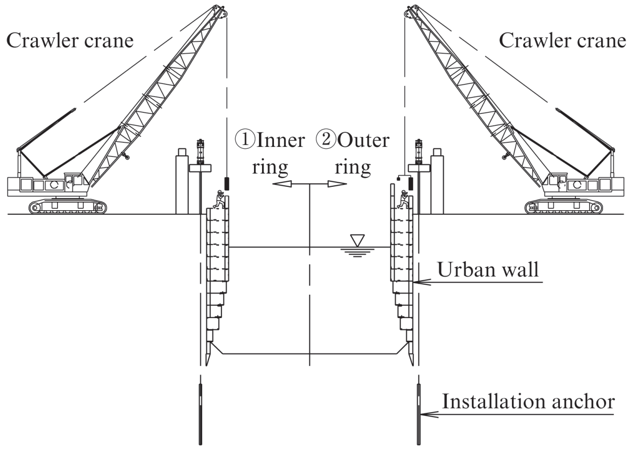

Fig. 9 Assembly of ring pieces

buoyancy due to installation of the bottom slab is converted to axial force in the upward direction by the stepped side wall shape, suppressing the hoop tension acting on the acute-angled tip of the cutting edge and the cutting edge as a whole.

5. Construction Method of Urban-Wall™ Method

5.1 Outline of Construction

Construction by the Urban-Wall method is the same as that of the conventional Urban-Ring method except for the ring assembly process. Although the construction period increases with large diameters and larger depth, body construction time can be shortened by approximately 30% in comparison with the caisson method and other conventional methods. In the excavation process, the construction period is shortened by increasing the number of excavators.

5.2 Ring Assembly

Assembly using double-walled inner and outer steel pieces, which is the most important feature of the Urban-Wall method, eliminates the need for inner scaffolds, which was necessary with the conventional method. In addition, if the inside steel pieces are assembled first, this also has the function of preventing personnel from falling into the shaft (**Fig. 9**).

After the inner and outer rings are assembled, the splicing materials are attached and concrete is poured. Because concrete pouring can be performed in piece units, construction is not controlled by the concrete supply capacity.

5.3 Excavation and Press-Fitting

During concrete curing after ring assembly, only the excavation work is performed. After concrete curing is complete, the press-fitting installation equipment is set up, and the Urban-Wall is press-fitted into the ground. Excavation work is continued simultaneously with press-fitting. Because the press-fitting force only acts on outside ring part during press-fitting, the press-fitting force can be transmitted directly to the tip of the cutting edge.

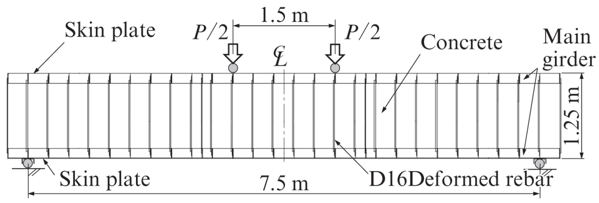

Fig. 10 1/2 scale bending test of the body

6. Confirmation Tests of Urban-Wall™

6.1 Bending Test of Body

In order to understand behavior under bending load of the composite-structure body, a 4-point bending loading test was conducted with a span of 7.5 m and a distance of 1.5 m between the loading points, as shown in **Fig. 10**.

The cross section of the test body was 1/2 scale, with dimensions of 1.25 m × 0.5 m. The plate thickness of the main girder was 8.7 mm (yield strength: 386 N/mm^2), the thickness of the skin plate was 4.5 mm (yield strength: 376 N/mm^2) and D16 rebars were arranged at intervals of 300 mm in the longitudinal direction as splicing materials. The concrete had a maximum aggregate size of 20 mm, slump of 8 cm and air content of 4.1%, and its compressive strength on the day of the test was 32 N/mm^2.

In the test, the specimen was first loaded to the design load (521 kN), which was calculated assuming the allowable unit stress of the steel material as 200 N/mm^2, and then unloaded, followed by loading until the

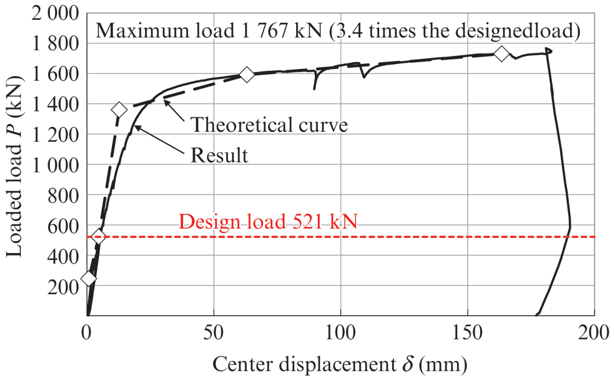

Fig. 11 1/2 scale bending test result of the body

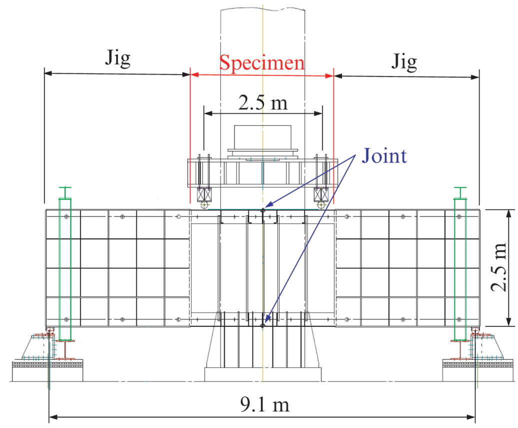

Fig. 12 1/1 scale bending test of the joint

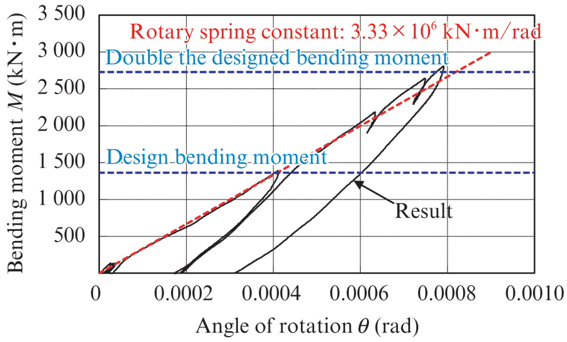

Fig. 13 1/1 scale bending test result of the joint

reaction force of the specimen decreased.

Figure 11 shows a comparison of the test result and the theoretical value calculated assuming a complete composite of the steel and concrete.

From Fig. 11, it can be confirmed that the segment body has a flexural capacity of 3.4 times the designed load. Furthermore, because the experimental results of the load-bearing capacity curve (P-δ relationship) is generally in agreement with the theoretical values, it can be understood that the body of Urban-Wall can be treated as a complete composite section.

The amount of rebars used as splicing materials was decided referring to the results of a similar 1/3 scale bending test conducted in advance of the 1/2 scale bending test.

6.2 Bending Test of Joint

In order to confirm the load-bearing capacity and rotational spring constant of the joint parts of the composite body, a 4-point bending loading test was conducted with a span of 9.1 m and a distance between loading points of 2.5 m, as shown in **Fig. 12**.

Assuming the full-scale (1/1) size, the dimensions of the specimen cross section were 2.5 m × 0.5 m. The thickness of the flat-type steel sheet pile used as the segment joint was 9.5 mm (yield strength: 407 N/mm^2), the thickness of the main girder was 16 mm (yield strength: 351 N/mm^2), the thickness of the skin plate was 9 mm (yield strength: 403 N/mm^2) and D32 rebars were arranged at intervals of 600 mm as splicing materials. The concrete had a maximum aggregate size of 20 mm, slump of 8 cm and air content of 6.0%, and its compressive strength on the day of the test was 23 N/mm^2.

The design bending moment was calculated by assuming the allowable unit stress of the joint to be 160 N/mm^2, and the joint was unloaded when the yield strain was exceeded, and the opening of the joint also exceeded 0.25 mm.

The test results are shown in **Fig. 13**. From Fig. 13, it was confirmed that the joint possessed load-carrying performance 2 times or greater than the design bending moment, and the rotational bending constant of the joint was 3.33 × 10^6 kN·m/rad in comparison with the design value of 3.00 × 10^6 kN·m/rad.

To examine the difference in performance accompanying changes in the segment dimensions, a specimen with a joint in the center of the specimen in Fig. 10 and flat-type steel sheet pile joints like those in Fig. 12 on the top and body edges was prepared, and a 1/2 scale bending test of the joints was carried out in the same manner as in Fig. 10. In the case of the 1/2 scale body, as in the case of the full-scale body, the joint possessed load-carrying performance at least double the design bending moment, and an error of about 10% was found in the rotational spring constant, as the test value was 6.00 × 10^6 kN·m/rad against the calculated value of 6.39 × 10^6 kN·m/rad.

6.3 Assembly Test

To confirm the assembly accuracy and ease of assembly of multi-segment boltless joints, pieces with an outer diameter of 13 m × 20 segments × 3 rings were fabricated, and an assembly test assuming an actual construction site was conducted (**Photo 5**). In the assembly test, five cases using different assembly methods were examined, and it was found that the

Photo 5 Assembly test

same level of assembly accuracy could be obtained in all cases. Actual assembly accuracy was within ±15 mm, while the tolerance for a diameter of ϕ10 m is normally ±20 mm.

The workability (cost, construction period) in construction of the inner and outer rings using splicing materials and the shape, construction procedure, etc. of the splicing materials were also confirmed.

Regarding the effect of seal material for large-depth construction on assembly accuracy and ease of assembly (workability), it was found that the seal material for large-depth construction could be squashed sufficiently by the bolts for tightening the splicing materials and had no effect on ease of assembly.

7. Conclusion

This report has presented an outline of the urban caisson method, Urban-Ring Method, which is a key technology for shortening the construction period under the difficult conditions of narrow ground and limited overhead space, particularly in urban areas. Applications of the Urban-Ring method have increased in recent years. Here, examples of use in temporary earth-retaining walls for bridge pier foundations, and innovative technologies for this application, are also introduced.

In addition, this report also presented an outline of the Urban-Wall method, which was developed beginning in 2014 in response to needs for construction of large-depth, large-diameter underground structures.

In the future, construction of underground structures with even larger depths and construction of larger underground structures are expected.

Methods for large-depth construction include the underground continuous wall, pneumatic caisson and press-fitted open caisson, among others. However, since all construction methods have issues when applied to even larger depths, development of safe, secure and certain construction methods is demanded.

In the construction of large-diameter underground structures, the risks of higher mechanical equipment capacity and maintenance increase dramatically. The risk of groundwater is also extremely high at larger depths, but at the very minimum, it is absolutely necessary to avoid manmade disasters.

Since the Urban-Wall method is a further evolution of the open caisson, which has little risk related groundwater, we are confident that it will become a standard risk-reduction method for large-depth and large-diameter construction.

In the future, we will work to popularize this method in actual construction projects, and will also further improve this method in line with excavation and earth-removal technologies being developed in parallel.

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