ABWR Construction Experience in Japan
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The construction of Kashiwazaki-Kariwa Nuclear Power Station Unit No. 6 and 7 (K6&7) owned by Tokyo Electric Power Company (TEPCO), have been in service since November 1996 and September 1997 respectively, and are the first ABWRs in the world. Hitachi, Ltd. and Toshiba Corporation took part in the projects and achieved safety construction in 52-month schedule from rock inspection to turnover in cooperation with TEPCO and other contractors with broad experience in BWRs. Taking advantage of experience of the Kashiwazaki construction, the ABWR construction methods realize to satisfy with requests from electric power companies and to fit site conditions. The Chubu Electric Power Company’s Hamaoka Nuclear Power Station Unit No. 5 (Hamaoka5) and Hokuriku Electric Power Company’s Shika Nuclear Power Station Unit No. 2 (Shika2), which are ABWRs, completed rock inspection in May 2000 and June 2001 respectively, and are under construction. The ABWR construction methods are proved their validity through four actual construction projects. Safe constructions with the highest quality have been advanced thus further aiming at the introduction of the latest technologies and contributing to reduce plant construction costs and also to shorten schedule.

KEYWORDS: ABWR, Construction, All-weather construction, Modularization, Open-Top construction

I. Introduction
The Kashiwazaki-Kariwa Nuclear Power Station of Tokyo Electric Power Company (TEPCO) is situated in northern end of Kashiwazaki city and extends next to Kariwa village in Niigata Prefecture in Japan. The site area is approximately 4.2 million square meters, and there are 7 nuclear power plants in the site. The total outputs amount to 8,212,000 kilowatts.

The first ABWR, Kashiwazaki-Kariwa Nuclear Power Station Unit No. 6 and 7 (K-6/7) started the construction in September 1991 and February 1992 respectively and started the commercial operation in November 1996 and September 1997. The ABWR K-6/7 project was performed by the international joint venture structure of GE, Hitachi, Ltd. and Toshiba Corporation under the contract with TEPCO. This paper describes features of the K-6/7 construction, standardization and rationalization for the ABWR construction derived from the K-6/7, and their application to the ABWR constructions being in progress.

II. Actual K-6/7 Construction
1. Construction Features
   (1) Construction Condition at Site
      The Kashiwazaki- Kariwa site (K-site) is in area where the winter climate is very severe with heavy snowfall and high seasonal wind. The bedrock, which supports the power block buildings, is rather deep at a depth of 25 to 40 meters underground. Detailed investigations and study on countermeasures against the construction conditions described above were required prior to the construction to secure good constructability and to perform the reduced construction schedule. Concerning the severe winter climate, countermeasures against the snowfall and wind, which causes decreasing work efficiency, were considered. Concerning the deep plant, countermeasures against the difficulty to carry-in equipment and bulk commodities into the building, which also causes decreasing work efficiency, were considered. Two principal construction methods were applied to K-6/7 construction based on the above considerations. One was the all-weather construction method, and the other was the modularization method.
      The all-weather construction method was designed to secure the work efficiency during winter, and was adopted the steel structure frames, temporary fabric walls and covered with temporary roof.
      The modularization method was applied to carry commodities into the building by a large-sized crawler crane (open-top construction method). The modularization method was not only applied to mechanical commodities (equipment, piping, valves, etc.) but also applied to civil commodities (rebar, steel structures, scaffolds, tower cranes, etc.).

   (2) Features of Construction
      (a) Construction Form
         K-6/7 were constructed under the international joint venture, GE, Hitachi, Ltd. and Toshiba Corporation, which was the first international joint venture for a nuclear power plant construction in Japan. Those three companies cooperated for developing, engineering and construction of the ABWR.
Concerning the construction, Hitachi and Toshiba took on GE’s scope as subcontractors, which made the construction at the site implemented by Hitachi and Toshiba substantially. Toshiba acted the representative for the construction of K-6 and Hitachi for K-7.

(b) Constructability for ABWRs
The RCCV (Reinforced Concrete Containment Vessel), which performs the containment vessel and the reactor building to be integrated, then the containment vessel work and the building work can be done in parallel. By the adoption of RCCV, the reactor building can be designed compactly, and it makes the construction period to be shortened. The RIP (Reactor Internal Pump) and the FMCRD (Fine Motion Control Rod Drive) are the most important equipment for ABWR and both equipment are installed at the bottom of the Reactor Pressure Vessel which is called lower drywell. The construction in the lower drywell was rather complicated and was implemented based on the detailed planned procedure.

(c) Reduced Construction Period
The principal construction methods adopted in the K-6/7 construction were the all-weather construction method and the modularization, which both methods were effective in improving the work efficiency and also in reducing the construction period. In addition to above principal methods, the following construction methods were applied in order to perform the reduced construction period:
- Open-top construction method for bulk commodities
- Expansion of the application of automatic welding machinery
- Application of integrated modules between civil components and mechanical / electrical ones.
- Expansion of deck plate method which makes the start of mechanical / electrical work earlier because of less curing duration for upper slab concrete

2. Construction Schedule
The ABWR construction milestones and principal paths are shown in Figure 1.

The critical path begins from the inspection of the bedrock of the Reactor Building and continues from the Reactor Building base mat completion through the RCCV and the Reactor Building up to operating floor and upper structure erection activity. After the Reactor Building Crane is available, the critical path continues through the Reactor Internals work and the system preoperational tests which use the Reactor Vessel, such as the ECCS injection test, the RPV hydro test, the CRD system test. After every construction work, inspection and testing are completed, the fuel loading and startup test is implemented.

K-6 performed the inspection of bedrock in Jul. 1992; the RPV was set on base in Aug. 1994, the RPV hydro test was performed in May 1995, the fuels were loaded in Nov. 1995 and the commercial operation started in Nov. 1996. The construction period from the bedrock inspection to the commercial operation was 51.5 months.

![Fig. 1 ABWR Construction Milestone Schedule](image)
K-7 performed the inspection of bedrock in Mar. 1993; the RPV was set on base in May 1995, the RPV hydro test was performed in Apr. 1996, the fuels were loaded in Oct. 1996 and the commercial operation started in Jul. 1997. The construction period from the bedrock inspection to the commercial operation was 51.5 months. The construction period was reduced about 6 months from the K-3/4 (Kashiwazaki- Kariwa Unit No.3 and No.4), which are of BWR with the steel containment vessel. Figure 2 shows the actual construction schedule of K-6.

3. Construction Method
(1) Construction Methods of K-6
(a) All Weather Construction Method

The all weather construction method was applied to K-6 as a drastic measure to improve the decreasing of work efficiency during winter at the site. The basic idea of this method is to cover the Reactor building with temporary roof. The all-weather construction method was constituted of the steel structure frames, temporary fabric walls and covered with temporary roof, which was divided into four sections and can be removed when a large component is carried into the reactor building. The construction crane system consisted of monorails and hoists, which were placed within the fabric wall, therefore, not influenced by snowfall and/or wind. The all-weather construction method made construction work free from the influence of weather and also created a factory-like environment with enclosed construction area and temporary cranes installed inside. And the all-weather construction method was verified that it is also effective against rainfall or sunshine in summer. Moreover, the steel structure provided easy access into the deep Reactor Building from the ground, which also improved the productivity of crafts and labors. The exterior and inside of the all-weather construction method is shown in Figure 3 and Figure 4 respectively.

Fig. 2 Actual Construction Schedule of K-6

Fig. 3 Exterior of All-Weather Construction Method
(2) Construction method of K-7

(a) RCCV Liner Large Block

RCCV constitutes reinforced concrete which is to resist pressure and steel liner which is to resist leakage. In RCCV construction work, reinforced concrete work after liner installation is a critical path. Lining plates were assembled in yard and carried in the building using large crawler crane in order to minimize the interfaces between civil construction work and mechanical construction work. RCCV lower block diameter is 29m, height is 21m and weight is 430 ton. Figure 7 shows its installation.

(b) Automatic Welding Method

The scope of the automatic welding method was largely expanded to aim at the improvement of welding productivity and enhancement of welding quality. The automatic welding method was applied to RCCV liners, large and small bore piping, instrumental piping, CRD scram piping, RPV nozzles, etc. The automatic welding ratio was achieved to 98% for RCCV liners, 60% for the large bore piping in the Reactor Building and 35% for the large bore piping in the Turbine Building. Figure 5 and Figure 6 show the circumstances of automatic welding method.

(b) Drywell Module

Mechanical installation work in RCCV is a critical path of nuclear island until RPV hydro test. The large module, which includes shielding wall, structural steel, equipment, piping, cable tray, HVAC duct, conduit and instrumental tube, was applied. This module is the heaviest in all modules, which is about 650 tons. This module was combined small module assembled at factory and assembled into large module at construction site. Before carrying in the RCCV, installation sequence was reviewed by 3D-CAD system. Installation status and 3D-CAD model of this module is shown in Figure 8.
(c) Mat Module

For base mat installation, installation sequence is very complicated with rebar and anchor bolts for RPV pedestal. It was needed long construction schedule. Therefore base mat module was assembled at site yard and set on the base using the large crawler crane to reduce schedule. This module weight is 460 ton. Installation status is shown in Figure 9.

![Fig. 9 Mat Module](image_url)

(d) Top Slab Module

Conventional construction method of top slab had several issues to solve. For example, interferences between timbering, which is to support concrete pouring load and mechanical components such as equipment, piping, etc. Also it is difficult to remove temporary construction material (e.g. timbering) in the congested layout. Modularization is applied to solve it. Permanent timbering was applied to support concrete pouring load and liners, rebar and embedded piping were assembled as a top slab module, and its weight is about 550 tons. At the review and study of planning, manufacturing and installation, 3D-CAD system was utilized and design information was exchanged to civil contractor. Therefore work efficiency and quality was improved. Installation status is shown in Figure 10.

![Fig. 10 Top Slab Module](image_url)

(e) Lower Condenser Block

In order to reduce the T/B construction period to follow R/B schedule, lower condenser block was assembled at factory. This block size is as follows:
- Height: 10m
- Width: 9.5m
- Length: 18.5m
- Weight: 600ton

This block was set by the special jacking device. Installation sequence was reviewed by using 3D CAD system and clearance between block and building was checked. Installation status of condenser is shown in Figure 11.

![Fig. 11 Condenser Lower Block](image_url)

III The latest ABWRs Constructions progress

Hitachi and Toshiba have has advanced ABWR construction methods to meet customer’s requirements and conditions on each site.

There are two ABWRs under construction in Japan. One is Chubu Electric Power Company’s Hamaoka nuclear power plant Unit No. 5 (Hamaoka 5), the other is Hokuriku Electric Power Company’s Shika Nuclear Power Station Unit No. 2 (Shika 2). Rock inspections in Hamaoka 5 and Shika 2 had completed in May 2000 and June 2001 respectively.

In Hamaoka 5, Toshiba takes charge of the nuclear island and Hitachi does turbine island. In Shika 2, Hitachi is a main contractor, covering both of nuclear and turbine islands.

(1) Hamaoka 5 construction

Figure 12 shows the summary schedule of Hamaoka 5 construction, which is equivalent to Level I schedule.

Main control room was in service by 6.9 kilo-volts power supply in December 2002. Currently, Toshiba is installing the reactor internals and conducting the utility sequence tests for the RPV hydro pressure inspection, that is scheduled in
September of 2003. Hitachi is mainly assembling the steam turbines and generator. Figure 13 shows the construction site of Hamaoka 5, which is in pre-operational test phase at present.

Fig. 13 Construction Status of Hamaoka 5

In Hamaoka 5, because construction site is relatively not spacious, tower crane, instead of crawler crane is applied to support open-top method, widely. Construction is performed and completed by each construction area, aiming at leveling a number of on-site workers. Widely-applied modules also help to reduce workers at site.

The Constructions photos of R/B and T/B are shown in Figure 14 and Figure 15 respectively.

(2) Shika 2 construction

Figure 16 shows the summary schedule of Shika 2 construction. The RCCV upper drywell, which is the heaviest module in Shika 2, and the two MSHs (Moisture Separator Heater), which locate in T/B were carried into building in February 2003. The RCCV Top Slab Liner Module and the RPV are scheduled to be installed in 2003. T/B is under steel frame building work to start Electric Overhead Traveling Cranes (EOTCs) in the end of 2003.

Figure 17 shows the construction status in Shika 2. Modularization is widely applied in Shika 2, to utilize a large crawler crane more efficiently.

For example, RCCV lower liners (Hitachi’ scope) and rebar (civil construction company’s scope) are assembled at site as a “composite module”. (See Figure 18.)

Also, the condenser upper shell and the heaters were prefabricated at the module factory. (See Figure 19.)
(3) Supporting technologies

3D CAD system, which has been already applied to design process, is improved and applied for construction planning at earlier engineering phase. This is aimed at more accurate and more efficient construction planning. As one of the results, animated construction sequence is shown on Figure 20. The following achievements are confirmed:

- The plan can be understood easily.
- The plan can be shared with others easily, which makes less coordination efforts.
- It can be easier to get into more detailed planning at design office.
IV Conclusions

Construction schedule at Kashiwazaki Kariwa was reduced by all weather construction method, 3D CAD system and modularization supported by large crawler crane. Furthermore, thanks to advice from electric power company, the corporative relationship between civil construction companies and mechanical construction companies was established. Under this circumstance, our construction method would be improved. Hamaoka Unit 5 and Shika Unit 2 are under construction now, based on the experience in the first ABWR.

Thus, ABWR construction methods have been proven their availability by these four reference projects.

In the future, as a social background, a number of workers will be decreased; worker’s wage will be increased; working hours will be decreased, and as customers’ needs, construction schedule and cost need to be reduced. To fit and satisfy with these background and needs, on-site work should be reduced; construction schedule should be planned high accuracy; on-site work should be more efficiently; project management at site should be more accurate. We believe that continuous enhancement for our construction methods described in this paper can be contributed drastically to achieve these targets.

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References