Advanced Construction Methods for New Nuclear Power Plants

A. Introduction

Relative to coal fired and natural gas fired power plants, nuclear power plants are more expensive to build but less expensive to run. This annex describes advanced construction methods to reduce nuclear power's construction costs, mainly by shortening the time needed to build a plant.

Each of the methods described below has been used in one or more of the projects listed in Table IV-1. None is unique to the nuclear industry, nor to any specific nuclear power plant design. Most are also used for other large construction projects such as fossil fuel power plants, large civil construction projects and shipbuilding.

Table IV-1: Reactors built recently using advanced construction methods [References: 1, 2, 3, 4, 5]

Reactor	Country	Construction period (months)*	Start of commercial operation	Type of reactor (approx. MW(e)) **
Kasiwazaki Kariwa-6	Japan	48	Nov. 1996	ABWR (1350)
Kasiwazaki Kariwa-7	Japan	48	Jul. 1997	ABWR (1350)
Lingao-1	China	60	May 2002	PWR (1000)
Lingao-2	China	62	Jan. 2003	PWR (1000)
Qinshan 3-1	China	54	Dec. 2002	PHWR (720)
Qinshan 3-2	China	58	Jul. 2003	PHWR (720)
Tarapur-3	India	75	Aug. 2006	PHWR (540)
Tarapur-4	India	66	Sep. 2005	PHWR (540)
Shin Kori-1	Republic of Korea	54 (planned)	Dec. 2010 (planned)	PWR (1000)
Olkiluoto-3	Finland	70 (planned)	Jun. 2012 (planned)	EPR (1600)
Kudankulam-1	India	84 (planned)	Mar. 2009 (planned)	PWR (917)

* The construction period is generally considered to be the time from the first major pour of concrete for the main plant building to the commercial operation date.

** ABWR = advanced boiling water reactor; EPR = European pressurized water reactor; PHWR = pressurized heavy water reactor; PWR = pressurized water reactor

B. Open Top Installation

Constraints on installing major components inside the reactor and containment building can have a major impact on the construction schedule. In the past, the walls of the reactor and containment building were constructed with temporary openings to allow the entry of large equipment. In open top installation (Figures IV-1 and IV-2), the reactor and containment building is built with a temporary roof with an opening through which major pieces of equipment, such as the reactor vessel and steam generators, can be lowered into position using very heavy lift (VHL) cranes. Today's VHL cranes can lift equipment weighing more than 1000 tonnes, with very long reach. Once the equipment is placed inside, piping and electrical systems can be installed at the same time that construction of the reactor and containment building is being finished, including the replacement of the temporary roof by a permanent containment dome.

Open top installation has been used successfully with modularization (see next section) to shorten construction schedules. VHL cranes add additional costs, but these are more than compensated for by the shortened construction time. VHL cranes also add to planning requirements as it is vital to ensure that they are strategically placed to conduct multiple lifting activities including the installation of heavy equipment in other buildings of the plant or to provide lifting capabilities for two units being built concurrently next to each other.

During the construction of Qinshan 3-1 and 3-2 in China, a VHL crane was used to position about 70 pieces of equipment (Figure IV-1), including steam generators which weighed 220 tonnes each (Figure IV-2), the pressurizer (103 tonnes), the reactivity mechanisms deck (43 tonnes), feeder frames (40 tonnes each), fuelling machine bridges (16 tonnes each) and major heat exchangers. It took just two days to install each steam generator instead of the two weeks required for traditional horizontal-access installation.

FIG. IV-1. Very heavy lift crane at Qinshan, China.

FIG. IV-2. Installing a steam generator at Qinshan 3-1 in China

Figure IV-3 shows a VHL crane lifting the 200-tonne containment liner double rings into place at Olkiluoto-3 in Finland, and Figure IV-4 shows the containment dome at Kudankulam-1 in India being lifted into position.

FIG. IV-3. Lifting the containment liner double rings at Olkiluoto-3 in Finland.

FIG. IV-4. Lifting the WWER-1000 containment dome into position at Kudankulam, India (Photo credit: NPCIL).

During the construction of Tarapur-3 and -4 in India, open top installation was used to position about 50 pieces of equipment, including the steam generators (Figure IV-5), moderator heat exchangers, several other heat exchangers, pressurizer, calandria (Figure IV-6), primary circuit headers and fuelling machine. The lowering and positioning of each steam generator was completed in less than a day, much less than the installation time of more than one month required by other methods.

FIG. IV-5(a) and IV-5(b): Installing a steam generator at Tarapur-3, India.

FIG. IV-6. Lifting the calandria at Tarapur-3 in India.

C. Modularization with Prefabrication and Pre-assembly

Prefabrication and pre-assembly of modules are construction techniques used in many industries, including nuclear power plants. A module is an assembly consisting of multiple components such as structural elements, piping, valves, tubing, conduits, cable trays, reinforcing bar mats, instrument racks, electrical panels, supports, ducting, access platforms, ladders and stairs. Modules may be fabricated at a factory or at a workshop at the plant site, and multiple modules can be fabricated while the civil engineering work is progressing at the site in preparation for receiving the modules. This reduces site congestion, improves accessibility for personnel and materials, and can shorten the construction schedule. It can also significantly reduce on-site workforce requirements.

Modularization also facilitates mass production of modules in the event that several reactors are being built at the same time. Mass production reduces production times and labour requirements. Modularization makes it easier to assure a controlled production environment, with associated improvements in quality and efficiency. It makes it possible to manufacture modules before the site itself is available, and, in the case of concrete, it facilitates the use of accelerated curing techniques.

The decision to apply a modular approach should be made in the conceptual design stage, and then it must be followed throughout the project, for detailed design, engineering, procurement, fabrication, and installation, through to the completion of commissioning. This allows equipment to be designed to conveniently fit into a module, and for modules to be sized to match the capacity of VHL cranes and transport routes to the site. A site accessible by sea can accept larger modules. For less accessible sites, sub-modules can be shipped to the site and then assembled into larger modules before installation. Modularization also affects testing procedures as many components can be initially tested at the fabrication facility to help eliminate potential faults before formal post-installation tests at the construction site.

Other impacts of modularization are: the need to complete the total plant design before fabricating modules; the need for factories or workshops to fabricate modules; earlier expenditures on engineering, materials and components for fabricating modules; the need for expensive heavy lift cranes; and the costs of transporting modules.

Modularization with prefabrication and pre-assembly has been used in combination with open top construction in recent construction projects for evolutionary water cooled reactors [1]. At Kashiwazaki Kariwa-7 in Japan the seven floors of the reactor building were divided into three modules and fabricated in a pre-assembly yard before the pieces were successively lifted into place by a VHL crane. The heaviest, most complicated module was the 'upper drywell super large scale module' which consisted of a γ-shield wall, pipes, valves, cable-trays, air-ducts and their support structures and weighed 650 tonnes (Figure IV-7).

FIG. IV-7. Installing the upper drywell super large scale module at Kashiwazaki Kariwa-7 in Japan.

At Lingao-4 in China the containment dome was assembled on the ground at the site and installed as a single module weighing 143 tons with a diameter of 37 metres and height of 11 metres (Figure IV-8). Previously, the dome would have been assembled by moving sections into position – a process that normally took about two months.

FIG. IV-8. Lifting the dome module into place at Lingao-4 in China.

The Shin-Kori-1 and -2 projects in the Republic of Korea modularized the fabrication and installation of the containment liner plate. This forms the inner structure of the containment building for the Korean Optimized Power Reactor. Normally, the installation process would have fifteen stages, each involving the installation of one containment liner plate ring. At Shin-Kori-1 and -2, except for the first ring, all the other rings were modularized into two-ring sections and installed with one lift for each section (Figure IV-9). The number of lifts is reduced, and the overall construction period is shortened. This method also simplifies connections with auxiliary buildings since connecting provisions, such as penetration sleeves for piping and electrical wire, are attached to the ring modules before installation.

FIG. IV-9. Modularization of the containment liner plate assembly at Shin-Kori-1 in the Republic of Korea.

As a final example of modularization, at Tarapur-3 in India, the prefabrication of piping was increased to 60–70%, compared with approximately 40% for previous plants in India. This reduced field welding by 30–40%.

D. Advanced Welding Techniques

Nuclear power plant construction involves numerous welds to connect both components of structures and components of pressurized systems. It also involves weld cladding, which refers to one metal being deposited onto the surface of another to improve its performance characteristics. Quality welding is both crucial and time consuming, and techniques to increase the rate at which weld metal can be deposited while maintaining high quality can reduce construction times. Recent advanced welding technologies that meet this objective include gas metal arc welding, gas tungsten arc welding and submerged arc welding.

In addition, automatic welding equipment that makes it easier to weld in narrow spaces can further decrease construction times. Automatic welding equipment has been used to weld titanium tubes to condenser tube sheets at Tarapur-3 in India and to weld piping at Kashiwazaki Kariwa-7 in Japan (Figure IV-10).

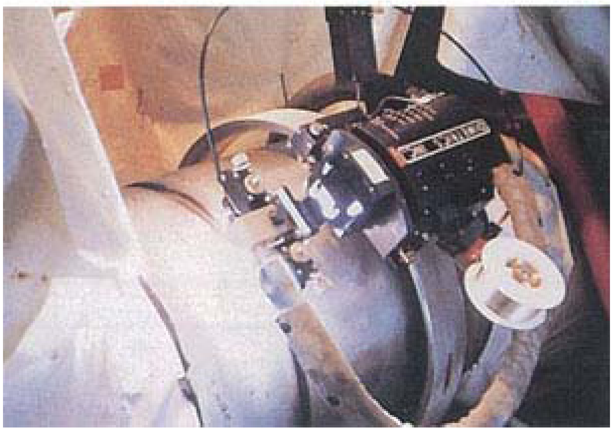

FIG. IV-10. Automatic piping welding at Kashiwazaki Kariwa-7 in Japan.

E. Steel Plate Reinforced Concrete and Slip-forming

Reinforced concrete is used in the foundations of nuclear power plants and in structures such as reactor containments, auxiliary buildings, turbine buildings and spent fuel storage areas. Conventionally reinforced concrete is fabricated in place using reinforcing bars ('rebar') with external forms to frame the structure prior to pouring the concrete. The time required to place the reinforcing bars and to construct and remove the forms into which the concrete is poured is considerable. It is a major part of the construction schedule.

Steel plate reinforced concrete is an alternative to conventionally reinforced concrete [6] and can be used for most floors and walls. The concrete is placed between permanent steel plate forms with welds to tie the steel plates, rebar and tie-bars together. The forms can include any necessary penetrations and piping runs. Because of structural credit for the steel plate–concrete combination, the amount of rebar may be reduced, and because the steel plate structure can be self-supporting, reinforced concrete sections can be modularized and prefabricated off-site, followed by placement and welding on site.

Figure IV-11(a) shows standard reinforced concrete, and Figure 11-IV(b) shows steel plate reinforced concrete.

FIG. IV-11(a): Reinforced Concrete

FIG. IV-11(b). Steel Plate Reinforced Concrete

FIG. IV-11. Comparison of reinforced concrete structures

Steel plate reinforced concrete has been used to significantly shorten construction schedules at plants recently constructed in Japan.

Construction schedules can also be shortened by slip-forming with modular floor design technology. Slip-forming is the continuous pouring of concrete at a very specific, calculated and monitored rate that is achieved by continuous hydraulic lifting and moving of a short section (preferably less than two metres) of formwork while inserting steelwork and pouring concrete through the top. Using slip-forming, vertical walls can be constructed at a rate of about two metres per day compared to a typical value of 1.2–1.5 metres per day without slip-forming. Slip-forming requires a heavy lift crane to lift the heavy steelwork that is inserted while the concrete is being poured.

Modular floor design and installation are used in conjunction with slip-forming for the walls. After the outer vertical walls of a building are installed by slip-forming, the modular floors can be installed through the open top of the building by means of a heavy lift crane. Modular floors consist of steel modules, which include rebar but no concrete, that are placed on supports embedded in the concrete walls during the slip-forming process. The modular floors, which are designed to be transported from the site assembly shop and installed by cranes, are welded to the supports embedded in the walls and then filled with concrete.

F. Rebar Placement for Reinforced Concrete

Rebar installation by individual placement of bars is quite time consuming. Large amounts of rebar are needed in the base mat, containment walls, containment dome, and structural walls of the reactor and turbine buildings. The use of prefabricated modular rebar assemblies for these areas can shorten construction schedules.

Automation is another way to speed the installation of rebar. There are several techniques. Figure IV-12 shows an automatic scaffold that moves vertically while horizontally feeding rebar into place. It both speeds the process and reduces labour requirements. Figure IV-13 shows a machine that automatically assembles rebar according to instructions from a 3-dimensional computer design model.

FIG. IV-12. An automatic scaffold and horizontal rebar feeding machine at Kashiwazaki Kariwa-6 in Japan.

FIG. IV-13. An automatic rebar assembly machine at Kashiwazaki Kariwa-7 in Japan.

G. Advanced Concrete Composition

In addition to these advanced methods for pouring and installing concrete, there have been recent advances in the composition of concrete to improve strength, workability, and corrosion resistance. Examples are self-compacting concrete, high performance concrete and reactive powder concrete. These are used not only in nuclear power plants but in other large civil projects such as bridges, highway, large buildings and dams.

H. All Weather Construction and Working around the Clock

To ensure that work can continue in all weather conditions, an all weather cover dome can be put over the reactor building. This method was used, for example, at Kashiwazaki-Kariwa-6 in Japan.

Working around the clock, both indoors and outdoors (see Figure IV-14), can save considerable time at critical stages of construction, for example during excavation, concrete pouring, structural steel erection, calandria vault construction and various welding activities.

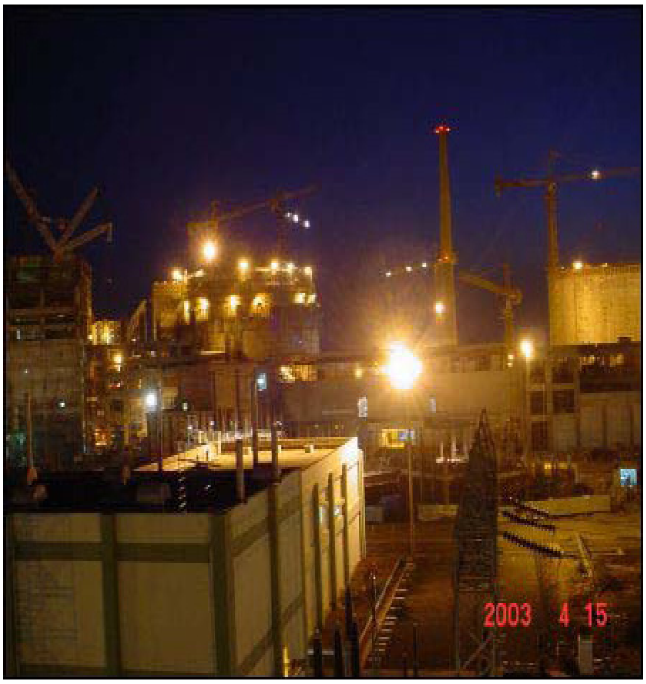

FIG. IV-14. Night view of site activities at Tarapur-4 in India.

I. Bending Small Bore Pipes to Reduce Welding Requirements

For small bore pipes, elbow fittings and their associated welds can be eliminated by forming bends within pipe lengths. Although the bending operation introduces costs of its own, the benefits include time and labour savings through reduced welding requirements and, because there are fewer welds to be inspected later, reduced inspection requirements.

J. Advanced Excavation Methods

Advances in excavation that can be applied to nuclear power plants include new equipment, such as large excavators designed for heavy workloads, massive grading and material handling, and large equipment for vibratory soil compacting. They also include precision blasting for excavating rock, which can reduce costs relative to more conventional mechanical excavation methods, for the reactor building, turbine building and other buildings. Several shafts are drilled in a precise pattern in the required area to be excavated and filled with explosives, which are then detonated. The possibility of using precision blasting depends on a site's geology and the plant's design as well as applicable regulations governing blasting.

K. Cable Installation

The installation of cables takes a significant amount of time and can be part of the critical path. 'Cable pulling' is the term used for the process of installing cables in cable trays (conduits) to connect plant equipment to power sources. The conventional method involves applying a lubricant to a cable (or group of cables) and pulling them into place with a rope. Improvements in this method involve better lubricants and cable rollers. Another technique reduces the need for cable pulling by splicing together the ends of cables that pass through different modules. Such splicing techniques are well established in the ship building industry.

L. Area Completion Schedule Management

The area completion schedule management method has been applied in the Republic of Korea at Shin-Kori-1 and -2. This approach replaces design and procurement schedules that used to progress system by system or, for a given building, floor by floor with an approach that divides each level of each building into zones. This allows more detailed scheduling of material purchase and the issuance of construction drawings to best integrate requirements in all zones. The approach is also used to schedule integrated installation work and set priorities among civil, mechanical, electrical and other needed work in each zone.

M. Computer Systems for Information Management and Control

The use of computer systems for information management and control is well established in the design, engineering and construction of large projects including power plants. For nuclear power plants the design and construction information must be maintained throughout the life of the plant including decommissioning. Computerized databases centralize all design information and allow quick access by all parties to design and construction drawings, equipment specifications, and inspection and testing data. The benefits of computerized information management and control systems are that they improve productivity through concurrent engineering, procurement and construction; allow drawings to be revised and accessed electronically; facilitate accurate determination of material quantities; and facilitate efficient procurement and construction management.

Such integrated systems can be used to develop 3-D models of:

- engineered piping and in-line piping components such as valves and strainers,
- raceways,
- structural steel,
- concrete,
- heating, air conditioning and ventilation components,
- equipment (tanks, pumps, heat exchangers, etc.),
- piping supports,
- piping and instrumentation diagrams, and

- embedded parts and plates.

Such 3-D computer models can then be linked to the schedule to provide '4-D modelling'. Specific deliverables at any stage can be extracted from the computer assisted design drawing model, including piping system isometric drawings, general arrangement drawings, and materials quantities, and the overall installation plan can be more easily visualized. During operation such models can be used to train operators and system engineers and to help nuclear safety engineers to visualize systems when evaluating performance and safety issues. For nuclear power plants, the system can also be expanded to track the inspections, tests, analyses and acceptance criteria that must be applied during construction to meet regulatory requirements.

N. Summary

The construction methods available for new nuclear power plants are generally the same as those used for other large construction projects. There have been numerous improvements in construction methods in the past few years, and recent experience in nuclear power plant construction has shown that those advanced methods are fully applicable and can help shorten construction schedules. Recent nuclear construction projects have been completed in as little as four years. The decision to apply some of these methods must be made in the conceptual design stage and then followed through consistently. Some advanced construction methods require earlier investments for factories and workshops and earlier outlays of funds to purchase materials, although they later save time and labour. Thus a shorter schedule does not necessarily mean lower total costs, and the relative costs and benefits for each of the methods summarized here must be weighed for each project independently.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Construction and commissioning experience of evolutionary water cooled nuclear power plants, TECDOC-1390, IAEA, Vienna (2004).

[2] Application of Advanced Construction Technologies to New Nuclear Power Plants, MPR-2610 (2004), prepared for the US Department of Energy.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Improving economics and safety of water cooled reactors: Proven means and new approaches, TECDOC-1290, IAEA, Vienna (2002).

[4] OECD NUCLEAR ENERGY AGENCY, Reduction of the Capital Costs of Nuclear Power Plants, OECD, Paris (2000).

[5] CHEN, S., IVANOV, A., KHAN, A., PETRUNIK, K., RICIUTI, R. AND WITTANN, K., Qinshan CANDU Project Open Top Construction Method, Proceedings of the 24th Annual Conference of the Canadian Nuclear Society, Toronto, Ontario, Canada, 8–11June 2003.

[6] A. OMOTO, TOKYO ELECTRIC POWER COMPANY, Improved Construction and Project Management, International Conference on Advances in Nuclear Power Plants (ICAPP) (2002).