Advanced Design and Construction Technology for ABWR

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Recently, many countries start planning to construct nuclear plants, and the electric power companies and the plant suppliers are acutely aware of the importance of the technical infrastructure required for construction planning and execution as this has a significant influence on construction costs. Plant suppliers in Japan have been focusing its attention on the efficiency of construction from earlier, because of its significant role in determining overall construction costs. Through continuous efforts to reduce fieldwork costs, we have developed unique technologies, especially the 3D-CAD system and other advanced construction technologies including modularization.

We, plant suppliers are now turning its attention to overseas nuclear plants construction also, and are developing more rational, economical, and global construction based on its vast experience in construction techniques.

In this report, the evolution of plant engineering methods and construction technologies, the present level of progress in construction, and technical developments for the future, are described.

KEYWORDS: ABWR, Plant Design, Construction Technology, Modularization, Construction Cost, Construction Management, 3D-CAD, IT

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Since the first nuclear plant was constructed in Japan in the 1960s, fifty-two nuclear power plants have been built, and three more are currently under construction. We, plant supplier like Hitachi, have played an active part in the fields of planning, design, procurement, manufacturing, construction, maintenance and refurbishment so far. Our unique technologies, such as the 3D-CAD-based integrated plant engineering environment and construction technologies are playing significant roles. Their achievements include construction of the world’s first ABWR, the Kashiwazaki-Kariwa Nuclear Power Plant Unit 6 and 7 of Tokyo Electric Power Company.

Construction technical field tends to be considered as not important, because it depends on worker’s skill, which is difficult to control. Recently, however, deregulation in the electricity market has led to further reductions in construction and fieldwork costs.

However, traditionally, we have focused on the construction field because of the high contribution it makes to overall construction costs. Through unremitting efforts to reduce fieldwork costs, we have developed two unique technologies.

- Integrated Plant CAE System

This system consists of a common engineering database used in all phases, viz., planning, design, purchasing, manufacture, and construction, and includes application systems.

- Construction Technology

New construction methods have been developed in conjunction with civil construction companies. These include open top construction, large-sized modularization, area construction, and parallel construction.

In this report, the evolution of “Design and Construction Technology” and their current status are described. Future technological development is also discussed.

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Construction Cost Breakdown

Currently, in the deregulated electricity market, power generation costs have become a critical issue. Although operation cost of nuclear power plants are the lowest in other power sources, their construction is the highest. Therefore, it is now vital that nuclear plant suppliers reduce construction costs. These efforts are now expanding into fieldwork, using advanced construction technologies, such as modularization.

Fig-1 shows a breakdown of the total construction cost of first ABWR, excluding the owner’s cost (e.g. site preparation). The cost of fieldwork constitutes 14% of overall construction costs, making it one of the largest single contributor to the plant supplier’s total cost.

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Fig-1 Construction Cost Breakdown

Plant suppliers in Japan have traditionally been focused on the reduction of fieldwork costs because of their large contribution to overall construction cost. Almost all our
construction technologies are aimed at fieldwork cost reduction, including reducing construction period.

Fig-2 shows construction costs and period for the plants most recently constructed by Hitachi, for example. Fieldwork cost and construction period have been reduced with our continuous efforts. Major applied technologies are also shown in the figure. In the next section, we discuss how these achievements were made.

Fig-3 shows how our construction related technologies; engineering tools and construction technologies have advanced as an example of Hitachi’s evolution. Our technologies can be divided into four generations.

First generation engineering tools are typified by 2-dimensional drawings made by hand. At that time, design was not accurate enough, which led to many piping configuration problems and design modifications had to made on-site to address these design deficiencies. In the second generation, a 1/10-scaled plastic model was assembled and the design accuracy was thereby somewhat improved. However, the model was too large and took a long time to modify when the layout was changed. An additional problem was that it was difficult to model small components in detail such as small piping. In 1985, as 3rd generation, we developed and introduced 3D Plant Layout CAD, instead of using a plastic model, to accelerate engineering speed and flexibility. From 1990, as the 4th generation, we have integrated sub-systems and this has enhanced overall engineering efficiency dramatically. We call this the 3D Plant Integrated CAE system, with construction management systems also being integrated into this system.

One of the dominant themes of the history of construction technologies has been modularization. To support and enhance this method, we have introduced a large crawler crane, and established a factory exclusively dedicated to module manufacture along with other innovations. Non-modularized components can also reduce fieldwork costs. An open-top method to carry these components into a building is now widely used, and a parallel construction method developed in conjunction with civil construction companies is also in common use.
We, plant suppliers have formulated a clear direction for
the next generation of tools and technologies. Section VI
describes this subject in detail.

. Plant Integrated CAE System

In this section, plant Integrated CAE Systems for one of
the achieved status of Japanese construction technical fields
are discussed, as an example of Hitachi’s one.

. Outline of the Plant Integrated CAE System

In the 1980s, Hitachi developed its proprietary
computer system, specially adapted to its plant design
method, and put it into practical use. Its advantages have
been fully confirmed as it has been applied on numerous
occasions to the construction of actual plants. In the
beginning, the 3D-CAD system simply replaced the plastic
model method. However, the 3D-CAD system has now been
optimized based on twenty years of experience. The
engineering database, together with the 3D-CAD, is now
regarded as a core-engineering tool, combining the design of
both upstream and downstream systems. The entire system,
comprising the design systems, the manufacturing support
systems, the construction support systems and, the
engineering database is called the "Plant Integrated CAE
System".

The outline of the Plant Integrated CAE system is
shown in Fig-4. Three-dimensional plant design including
piping layout is performed utilizing upstream design
information such as a plot plan and system design data.
After a careful review of the plant design,
fabrication/installation information such as shop and field
weld data is added to the 3D data. Fabrication design is
performed using the 3D data stored in the database, creating
fabrication drawings, purchasing data, and input data for
computer controlled fabrication machines. 3D design data
and fabrication data are used for construction planning,
which includes such work as designing temporary facilities,
planning a construction schedule, planning a detailed
construction sequence, and reviewing the moving range of a
crane.

In addition, the Plant Integrated CAE system is linked
with approximately ten computer servers in Hitachi’s design
office and local construction offices. Although graphics
workstations were needed for 3D-CAD until a few years ago,
the rapid improvement in PC performance now permits their
general use. The system is connected to hundreds of PCs
throughout Hitachi engineering office, and it is used in the
design office, in the factory, at construction job sites, in
sub-vendors’ offices, and also in customers’ offices.

. Plant Layout Design Using 3D-CAD

. 3D Design System and Database System

Fig-5 shows the plant 3D-CAD system architecture,
which includes the 3D-CAD database, 3D layout CAD
program, and the input and animation functions.

The detailed arrangement of equipment and piping has
been crafted in such a way that it harmonizes with the
general arrangement of the building. In the process of
creating a layout plan with 3D-CAD, various checks are
made by employing the design support function of the
software. This ensures a quality high-speed layout design for
piping. The plan is fundamental to assuring safety, operability, maintainability, and practicality. Therefore, the plan is checked in detail to ensure that it satisfies all requirements of plant equipment and operations. Planning of the building structure and auxiliary facilities is carried out simultaneously, and a synthetic arrangement adjustment (“composite arrangement”) is made to integrate the concrete design policy with the requirements of all relevant specialist disciplines.

For the fabrication design, manufacturing, and fabrication itself, information is created using the design system, and stored in the 3D database. This information includes such items as material specifications, welding procedures, and inspection requirements, and is used for material and parts purchasing, and production of pipe fabrication drawings in the downstream design process. Importantly, the database has improved the cooperation between the engineering, manufacturing, and construction specialists by facilitating the sharing of information and the delivery of data with a groupware system and a document management system.

![](Fig-5 The Plant 3D-CAD System)

- Review and evaluation system

The walk-through function enables engineers to visually check the plant layout as if they were walking through the actual plant. The major purpose of walk-through is to check operability and maintainability of the plant. For example, any interference in the maintenance space or in the access space where an object is to be mounted or dismounted can easily be reviewed. Also, several other simulation functions are used so that the engineers and the customer can review the layout design on 3D-CAD from various perspectives (accessibility, equipment disassembly/re-assembly, work volume for In-Service-Inspection, etc.), taking ease of maintenance for all the components of the plant fully into consideration.

Furthermore, “Remote CAD Review” is a walk-through simulation function that has been made accessible via the Internet, allowing views of each operation to be observed by personnel at different locations (for example, at the construction site and the Hitachi engineering office). This capability can be used together with a video conferencing device for review meetings (see Fig-6).

![](Fig-6 Remote Review Concepts)

### 2.2 Detailed Design and Fabrication

After reviewing the plant layout and finalizing the information and the specifications using the information from the 3D-CAD database, pipe fabrication drawings are created. Here the automatic design application of the CAD system improves the reliability and quality of the design, while reducing the man-hours needed to create the drawings. The features of the system are shown below.

1. Automatic specification of pipe parts. (fittings, gaskets, bolt-nuts, etc.)
2. Automatic generation of manufacturing information
3. Automatic generation of bill of quantity information
4. Automatic generation of dimensions and annotations
5. Automatic generation of NC (Numerical Control) data for pipe fabrication
6. Automatic generation of shop and field inspection information
7. Cooperation with construction planning and management systems

Production information is added to the piping design data automatically, and is stored in the production control database of the pipe fabrication shop. Based on this information, piping production is optimized in a master schedule and is broken down into weekly and daily schedules. Moreover, a “work instruction” document is sent to a work team and NC data for a production machine are generated and published from the database. Finally, a “work actual result” is fed back into the database for management purposes.

3D-CAD is also an indispensable tool in the modularization process. Modularization simplifies installation work by using “modules”. A module is made up of factory pre-assembled components, such as equipment, piping, valves and platform, and it is installed with a very large crane. Modularization has the following advantages: shortening the construction period, reducing construction cost, and improving safety and quality. (Modularization itself is discussed in Section V.)

By using 3D-CAD, a module design can be carried out...
in parallel with a layout design, achieving a more optimal plan. Moreover, key information on factors such as module manufacturing and parts delivery schedules is integrated into the database, and can be used at the module factory.

### 2.3 Engineering Management

As mentioned above, each design tool plays an important role in nuclear plant design over the many stages of planning, engineering and construction. The complexity and the scale of such projects generate major design challenges, beginning with the initial design and continuing throughout the construction process. Hitachi’s engineering management method meets these challenges by applying the following policies:

1. Sharing current design information on the database
2. Management of design adjustments in the database and groupware
3. Clarification and control of design status
4. Sharing engineering, purchasing, and construction schedules

These advanced functions are described in the following paragraphs.

- **Sharing engineering information**
  
  Each section responsible for the design of a portion of the layout plan shares information on the 3D-CAD database. This is important as it allows adjustment of the design schedule between related sections, which benefit from sharing information such as pending clarifications, design knowledge or expertise, and design example references.

  In the 3D-CAD virtual world, an engineer can place an annotation “balloon” in key locations, containing engineering history information such as problems encountered, interferences or bad designs, and changes in the prospective schedule plan, as well as client review comments. This makes it possible for any engineer to refer to the design know-how (previous layout examples, examples of previous faults, design indicators, etc.) accumulated over many years. These balloons are classified so that their form and color show the relevant section and the design status at a glance.

- **Schedule and status control system**

  In the area of piping design, information management is very important. Necessary information for piping design such as P&ID data, equipment nozzle connection, valve arrangement, piping design conditions, etc. should be specified in detail, and design and delivery status should be carefully managed and monitored. The 3D-CAD database is linked with other databases, such as system design, valve design and purchasing, and equipment design, and is also interactive with the piping production control database, and with the construction planning and management database. The status of the delivery of data, design and production status, and target date information are stored in the database and are sent to the relevant specialists using a groupware system. In this way, each specialist is kept updated on the progress of the others and all can check each other’s work situation. The outline of the schedule and status control system is shown in Fig-7.

![Fig-7 Schedule and Status Control System](image)

By specifying a product’s site delivery date, the database system automatically sets up the product manufacturing or purchasing schedule and the engineering schedule, including the downstream drawing publishing deadline, and also upstream 3D-CAD data or system design data for finalizing deadlines. This makes it possible for the engineers to clarify the status of a range of issues such as a delay in the work, a deficiency in the data, or the deadline for delivery of the data. Also, an engineer working on the downstream design can assess the appropriateness of the upstream design data by referring to the planning completion status registered in the database.

### 3 Construction Management

The construction support system has been developed to make indirect work at the site more efficient by utilizing 3D CAD data. It enables us to reduce paperwork and to support effective project management, which includes a Plan/Do/Check/Action cycle. Fig-8 shows an overview of our construction support system.

![Fig-8 Construction Support System](image)
1. Schedule planning system

This system provides support for 3-monthly and 3-weekly schedules that are automatically created by breaking down the construction area schedules. Achieved schedules, which are input by workers or foremen, are summarized into a higher-level schedule. This contributes to higher efficiency in making and evaluating the construction schedule. Moreover, this system is linked with the “work instruction system” and the “inspection support system”. It enables us to submit work instructions and inspection requests in coordination with the construction schedule.

2. Document control system

This system manages document control functions, which are acceptance of document, distribution to several sections at the site office and also document return and disposal.

3. Commodity control system

This system supports the management of products and material delivered to the site based on electronic invoices. This provides warehouse controls such as receiving, checking and inventory management, which originate from the electronic supply list issued by the design section.

4. Work instruction system

Foremen download work instruction data, which is matched with 3-weekly or 3-monthly construction schedules and after review and approval by the supervisors and chief supervisors, the instructions are conveyed to workers via palm computer. Achieved results are uploaded via the palm computer or directly input by workers and stored in the database. After supervisors’ approval, the results are forwarded to the quality control section as inspection requests.

5. Inspection support system

Inspectors download inspection request data to a palm computer or print it out, and inspection is executed. The inspection results are input by uploading via the palm computer or by direct input, and stored into the database after receiving the quality manager’s approval.

6. Labor control system

This system manages all field workers’ information, such as their employing company and work qualifications (welding, permission to use some special equipment, etc).

7. Progress evaluation system

This system evaluates delivery progress and work progress by construction area, building, system and subcontractor.

## Construction Technologies

In this section, construction technologies for another achieved status of Japanese construction technical fields are discussed, as an example of Hitachi’s one.

### 1 Construction Strategies

To introduce particular construction methods, construction costs are broken down into three major parts: “Direct costs”, “Construction expenses” and “Indirect costs”. Each of these is reviewed to determine where costs can be reduced, and to select the construction methods that will produce the lowest overall cost.

1. Direct costs

Direct costs are defined as the cost of labor. This is calculated as the product of construction quantity, the manpower required per unit of construction (e.g. manpower for a welding point) and the unit labor cost. Unit labor cost is assumed to be constant from the time when the construction site is decided. To reduce direct costs, it is necessary to reduce the construction quantity and to achieve higher productivity for direct work. Reduction of construction quantity includes removal of construction work from the site by applying the modularization method. To achieve higher productivity, it is necessary to minimize rework through detailed and accurate pre-engineering before starting construction and by introducing automated equipment.

2. Construction expenses

Construction expenses include the cost of scaffolding, rest rooms, cranes and the like. In this paper, the cost of the equipment (such as large crawler cranes) required to achieve a shorter construction schedule is not touched on. Construction expenses are planned based on the manpower peak. Therefore, reducing the manpower peak, i.e. more even distribution of manpower, is an effective way of reducing such expenses. Parallel construction and the open-top method are useful in reducing the manpower peak because they enable us to start our work earlier than conventional methods.

3. Indirect costs

Indirect costs are defined as personnel expenses for supervisors, foremen, schedule-managing engineers,
quality-management engineers and so on. Because nuclear power plants involve much higher volumes of construction materials and have stricter quality requirements than any other type of power generation plant, there is much more paperwork. Therefore it is necessary to use information technology to reduce this paperwork and other administrative overheads, thus improving the efficiency of indirect workers. The practical construction support system, already described in this paper, has been proven to be effective.

In summary, the construction methods that need to be established are as follows;

1. Modularization
2. Open-top method
3. Parallel construction

These methods are described from the next section.

### 2 Modularization Technology

Modularization technology is one of the construction methods, and involves pre-assembling the components (equipment, piping, piping support, valves, platform structure, etc.) in a dedicated area at the factory or yard on-site, and installing the components at the site at just the right time. **Fig-9** shows an example of a module.

![Fig-9 MSR Drain Tank Module Including Piping, Valves, Platform](image)

Module construction has the following advantages.
- Shortening the construction period
- Reduction in the number of field workers on-site
- Reduction in construction cost
- Improvement in product quality and work safety

Hitachi has been applying and developing modularization technology since the early 1980s. At the beginning, however, there were some limitations and these included module size and applicable area, among others. Hitachi has been upgrading its modularization technique based on its many years of experience and through maximizing the benefits available through the optimal utilization of information technology. **Fig-10** shows the chronological development of Hitachi’s modularization. At this time, about 200 modules are available and being used, which reduces construction costs, and shortens the construction period.

The modularization process can be broken down into three categories or phases, as follows.

#### Engineering

At the beginning of module engineering, it was planned after each modularized component’s engineering would be finished, so that many coordination of activities and re-engineering were caused.

Thanks to significant advances in our 3D-CAD Systems, we have developed and applied the sub-system for module engineering. By maximizing the practical use of this tool, it has become possible to formulate a module strategy based on the experience at early stages of engineering. Since work on each module is integrated with other work being performed in the module’s area, it has become possible to harmonize and coordinate activities to greatly reduce re-working.

#### Manufacturing

At the beginning, there was no base for module manufacture and each module was constructed at different work sites. This led to several problems such as difficulty in controlling delivery and high transportation costs.

To solve these problems, we established a module factory, and concentrated our manufacturing work there. This allowed us to reduce transportation costs.

Furthermore, we were able to rationalize and create a highly efficient manufacturing process, and the high-speed network enabled us to perform engineering and manufacturing concurrently.

#### Installation

The scope of modular construction was expandable by applying an “open top method” and “parallel construction” coupled with detailed information interchange with civil contractors. Moreover, the limitation that had previously been imposed on module size was mostly overcome through the introduction of a large crawler crane.

**Fig-11** shows how the application of modularization reduced the peak number of field workers.
Open-Top and Parallel Construction Method

Recently in nuclear power plant construction, building work and equipment installation are executed concurrently as “Parallel Construction”. Hitachi is responsible for the installation of equipment. With conventional construction methods, the Company could not perform tasks such as the installation of equipment, piping and valves until 2 or 3 months after pouring slab and wall concrete. However, the Company has implemented a construction method to shorten the critical path by performing installation work and building work in parallel.

Parallel construction has become a basic construction method for Hitachi and the Company has concentrated its efforts on increasing the parallelism of installation and construction. Modularization and the open-top method are essential for parallel construction, as explained in the following paragraphs.

Open-Top Method

In the open-top method, mechanical equipment, pipes, valves, operating stages or modules and blocks are carried in before construction companies complete the wall work. Equipment, operating stages and modules are aligned during intervals between ceiling concrete pouring and the start of full-scale installation. Then hooks, hangers and monorails are fixed on the ceiling. Finally, pipes are hung along the piping route. Fig-12 shows pre-installation sequences.

Pre-carrying in before the start of installation is essential for shortening the construction period. In addition, Hitachi coordinates the installation start date with civil construction companies. Equipment and drawings for construction must be delivered to the site to maintain the installation schedule. Therefore, the Company puts a great deal of effort into planning the delivery schedule and using it as an input for the equipment-manufacturing schedule. The area-by-area construction method allows us to determine reliable delivery schedules.

In addition, both the parallel construction and open-top methods need to be closely coordinated with the civil construction companies. To support this, we exchange 3D CAD data with each other and work hard to achieve more efficient and accurate pre-planning. Fig-13 shows an example of equipment layout using the open-top method, integrated with the use of 3D-CAD data.

In the next section, other coordination support activities are described.
detailed understanding of the interface with civil construction companies, and we can then formulate the best possible plan for installation procedures, integrating them with the civil construction schedule. Moreover, workload estimation for every area results in an accurate manpower-planning chart.

5. Latest ABWR Construction Project

All the plant engineering methods and construction technologies that were introduced in this report are being utilized at both construction sites, and every thing is going smoothly.

Hamaoka Nuclear Power Plant Unit 5 of Chubu Electric Power Co. (Hamaoka 5) and Shika Nuclear Power Plant Unit 2 of Hokuriku Electric Power Co. (Shika 2) are under construction in Japan. **Fig-14** shows the present status of construction at Hamaoka 5. Progress in the project had reached 94% in June 2003, and at Shika 2, it had reached 65% (See **Fig-15**).

In the recently deregulated electricity market, nuclear plants need to be competitive with all other types of power generation, and customers must be able to reduce construction costs. In particular, because construction period is one of the most significant contributors to construction cost, this period needs to be further reduced. Corresponding to these needs, various studies are carried out not just in mechanical construction, but also in civil construction, which is a key element of most critical paths. **Fig-4** also shows construction technologies of next generation, which we turn to.

First, instead of just conventional reinforced concrete (RC), architecture is also proposed and examined that is based on extensive use of iron, such as a steel structure + reinforced concrete (S+RC), and steel plate reinforced concrete (SC) and a hull-structure. These are shown in **Fig-16**. To shorten the construction period, "Modularization" is the keyword that even determines which building structural types are selected. We are undertaking studies with civil construction companies to enhance our overall construction capabilities. For example, a compound module under study for the next generation is shown in **Fig-17**.

Second, large power plants with capacity of 1000-1400MW have been mainly designed and constructed. However, a need for medium sized plants has recently arisen for the following reasons;

- Reduction of investment risk
- Stable electricity supply through multiple plants (sequential construction and outage)
- Suitable for developing countries that do not have a high capacity electrical supply grid

Medium sized plants have a higher unit construction cost than large ones. Therefore, it is critical to reduce construction costs. To do this, system simplification and standardization need to be investigated along with a reduction in construction period and an overall reduction in costs. The advanced construction technologies we have developed through our experience with large plants are being adapted to achieve this.
At last, to manage construction overseas efficiently, the following are being investigated:
- More integration and standardization of the engineering database and infrastructure that enables us to share various information through the Internet.
- Development of a construction management system in conjunction with overseas vendors

The above should be part of a project management system, which includes the functions of risk and schedule management. These systems can also be effectively utilized in domestic projects.

Conclusion

In this report, the evolution of plant engineering and construction technologies, the present level of construction progress, and future technical developments have been described.

The social environment and customer requirements in nuclear construction are very demanding. In meeting these requirements, we, plant suppliers, have the following advantages.

1. Many notable achievements and a vast amount of accumulated experience in this kind of construction
2. Advanced technology in the areas of plant engineering and construction, focusing on the construction field.
3. All stages of plant construction are fully integrated and coordinated

To maximize the benefit of the above advantages, development strategies and targets for our next domestic plants and overseas plants need to address the following two points:

1. Development of an integrated and advanced engineering support system which will facilitate optimal global plant engineering and construction management, and establishment of its infrastructure.
2. Further innovation of advanced construction technologies such as modularization, integrated with building structure and construction methods.

We have already made progress in reaching these targets. We believe strongly that the future will be opened through our commitment to these goals.

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