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# A Study on Nonconformance and Construction Method Improvement for Nuclear Power Plant

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## 1. Introduction

### *1.1. Background*

South Korea has 23 reactors which generate 20.5GWe that is 22% of South Korea's total electrical generation capacity, and 29% of its electricity output.[1] South Korea has plans for continued expansion, to increase share of nuclear generation and export nuclear power plant to the world.

In 1978, South Korea's first commercial nuclear power plant began. From that point, South Korea has developed design, construction and operation technology. Now advanced power reactor was developed by domestic technology, and finally exported to abroad.

In order to place the current nuclear power industrial base, construction has played a big role. Without magnificent construction technology, it would have been impossible to get a safe nuclear power plant on time and in budget.

Construction industry occupies very large portion of the economy in South Korea and it has been a core of South Korea's economic growth. With a competitive construction industry and advanced nuclear power plant construction know-how, South Korea could provide safe and reliable nuclear power plants in domestic and world.

However there are many repairs and number of corrective actions are in actual construction.

Thus, this paper suggested the result of nonconformance and construction method improvement for nuclear power plant.

### *1.2. Introduction to Research Problem*

In South Korea's nuclear power plant project, project development, procurement and operation is usually performed by government owned company. And construction is performed by contractors which are private construction companies.

There are several contractors which can perform a construction a nuclear power plant and they are trying to develop the advanced technologies for not only a commercial income but also competitiveness.

Even they have their own construction technology and know-how, general types of South Korea's nuclear power plant is limited. So when new nuclear power plant is under construction, similar nonconformance is issued every time.

This paper focused on the nonconformance about nuclear power plant construction, and find characteristics and solution. In addition, for more competitive nuclear power plant construction, this paper reviewed improvement of nuclear power plant construction method.

### *1.3. Objective and Limitation*

Occurrence of nonconformance during construction is one of big obstacle to successful construction. Nonconformance issue makes impossible to perform following construction process and it delays whole project progress. Delay of project cause to more cost and it could make over budget situation. Moreover many of nonconformance issues mean low quality of project which is critical for nuclear power plant. This paper reviewed several nonconformance issues and find out common cause, and finally suggested solution about it.

And now we have to focus on world nuclear power plant market with competitive project management ability. To lead the market, design capability is important, but more important is the construction which implements the design. So this paper suggested several construction method improvements which can save cost and time with maintaining high quality.

Most of nonconformance issues, this paper studied come from OPR construction project which is very similar to APR. And this paper limited a study about nonconformance issue and construction method improvement in CP-A category.

## 2. Nonconformance Case Study

### *2.1. Study Target Range*

The study target range for nonconformance case was set from first concrete pouring of main building to end of project. The total duration is approximately 52 months which is general construction period for one unit of OPR.

### *2.1. Nonconformance Proportion*

There are various construction works during nuclear power plant project but mainly CP-A1 category which is structural work for facility structure.

Main buildings such as reactor containment building, auxiliary building and compound building are designed with reinforced concrete structure which has a lot of embedded items in structure.

Table I. Nonconformance Proportion

| | Number of Nonconformance | Proportion (%) |
|---|---|---|
| Miscellaneous Steel | 47 | 62 |
| Concrete | 16 | 21 |
| Reinforced Bar | 9 | 12 |
| Other | 3 | 4 |

As shown in table I, nonconformance of miscellaneous steel is most frequent work during construction of nuclear power plant. In miscellaneous steel work, there are two main works. Embedded plate is an item for fixing supports inside building and the other one is anchor bolt which is for fixing equipment. All of embedded items should be set up before pouring concrete which requires high precision. So most of nonconformances are issued with exceeding allowable error.

Nonconformance of concrete and reinforced bar has another main portion in whole work. Most nonconformances are about quality problem that is caused fail of field management.

*2.3. Nonconformance Types*

In miscellaneous steel work, missing installation and exceeding allowable error is main type of nonconformance. In concrete & rebar work, surface defects, concrete crack and difference with drawing are main type of nonconformance.

Table II. Nonconformance Types Base on Work

| | Nonconformance Types |
|---|---|
| Miscellaneous Steel | - Missing installation of embedded items<br>- Exceeding allowable error of embedded items<br>- Type error of embedded items |
| Concrete | - Concrete surface defects<br>- Concrete crack<br>- Difference with drawing<br>- Water leak from concrete structure |
| Reinforced Bar | - Difference with drawing<br>- Cut rebar randomly<br>- Bending rebar |
| Other | - Exceeding allowable error of structural steel<br>- Missing installation of water stop<br>- Use substandard materials |

Among nonconformance types base on cause, exceeding allowable error has almost half of whole portion. Most of exceeding allowable error occurs with especially anchor bolt which requires high precision. For example, tolerance of NSSS(Nuclear Steam Supply System) anchor bolts is extremely severe, so most of NSSS equipment's anchor bolt tend to exceed tolerance.

Table III. Nonconformance Types Base on Cause

| | Number | Proportion (%) |
|---|---|---|
| Exceeding allowable error | 40 | 53 |
| Concrete quality | 14 | 18 |
| Difference with drawing | 11 | 14 |
| Other | 10 | 13 |

Concrete quality issue is another main cause of nonconformance. Concrete filling failure, so called honeycomb problem is frequent nonconformance and water leakage from concrete structure is another issue.

Table IV. Nonconformance Types Base on Solution

| | Number | Proportion (%) |
|---|---|---|
| Use as is | 39 | 52 |
| Repair | 33 | 44 |
| Rework | 3 | 4 |

"Use as is" and "Repair" are most widely applied in nonconformance solution.

Most of "Use as is" cases are relate to embedded items in concrete. For example when the location of anchor bolt for equipment is different with drawing, usually use the anchor bolt without repair because of difficulties of relocation. But for subsequent work, the location of anchor hole will be relocated with formal procedures, so called FCR(Field Change Request). The figure below shows example of "Use as is" for wrong located anchor bolt.

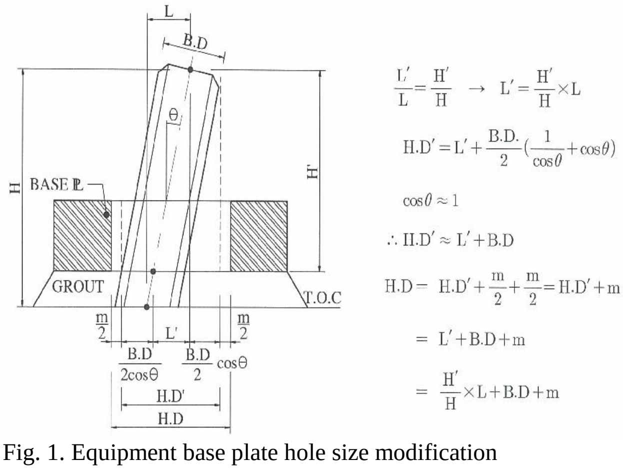


Fig. 1. Equipment base plate hole size modification

"Repair" case is mostly related to concrete nonconformance. Concrete surface defects and cracks must be repaired for soundness of concrete structure and usability. For concrete repair, there are various methods but non-shrinkage mortar and cement paste are most common repair method. The figure below shows example picture of "Repair" for concrete nonconformance.

Fig. 2. Concrete honeycomb around embedded plate

From nonconformance case study, we could find characteristic and cause of nonconformance. Base on this study we can find the way of reducing nonconformance and through this we can save the cost and construction time.

The table V. below shows allowable error of embedded items. If result of survey on embedded items is not in allowable error, nonconformance is issued. So to reduce error on embedded items following measures should be in practice.

Table V. Allowable Error of Embedded Items [2]

| | Allowable Error | |
|---|---|---|
| Embedded Plate | ±1 inch | Corresponds to strip embedded plate |
| Anchor Bolt | ±1/8 inch<br>±1/4 inch | ±1/8" for plane<br>±1/4" for elevation |
| Sleeve | ±6 inch | Limited to conduit sleeve |
| Back-up Bar | ±1/2 inch | ±1/2" for plane |

First of all, the latest version of drawing should be used by field engineers and workers. Construction of nuclear power plant is a kind of fast track project whose design can change during construction. So it is very important to keep latest version of drawing to escape from re-work.

Furthermore field survey has to be performed before and after concrete pouring. After pouring concrete, embedded item survey must be performed as fast as possible not to have delay with following work.

More aggressive way is using template for equipment anchor bolt and more simplified design for embedded items. Simplified design means combining similar type of embedded items and reduce number of embedded items.

## 3. Improvement of Construction Method

There are several advanced construction methods for nuclear power plant construction. This paper will cover characteristic and applicability of those construction methods.

### *3.1. Very Heavy Lift Crane*

Nuclear power plant has a lot of heavy equipment in the buildings such as reactor pressure vessel, steam generator, emergency diesel generator, and overhead crane. And the construction duration can be shortened when large assemblies are used to the schedule critical components. As a result heavy modules are applied for cost and schedule saving.

When we apply very heavy lift crane we have to take account of the followings. A very heavy crane could be one of long-lead items and restricted by the transportation limitation. And it requires wider construction space.

This method is used in large-scale construction projects, including nuclear power plants recently completed or under construction in Japan, Taiwan, and China. Using Open-Top Installation and Modularization techniques applied with very heavy lift crane, these plants have been built in less than 72 months. As a result, construction costs have been reduced 10 to 20%, or approximately $100 million. [3]

To apply this method, preliminary plan for heavy lifting is very important. For example, design of lifting lug and weight distribution ratio simulation must be considered carefully.

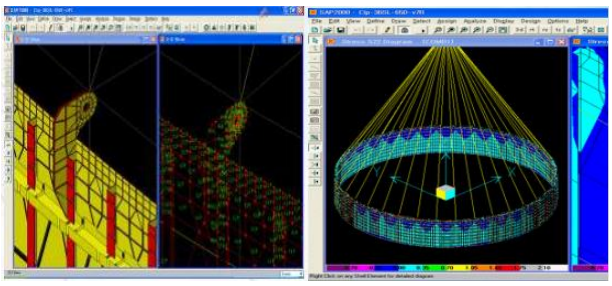

Fig. 3. Design of lifting lug and weight distribution simulation

### *3.2. Modular Construction*

Modular construction provides a cost saving and a schedule saving, if it is applied appropriately. So it needs to be evaluated based on the job site conditions. Modular approach for the nuclear power plant is different from the other fossil or chemical projects.

Modular construction can reduce schedule and field work and leveled on-site manpower. And it increase productivity and quality under factory environment. But modular construction increase engineering for modular, temporary support structure, and lifting requirements.

An example of modularization is the fabrication and installation of the containment shell liner plates at the Shin-Wolsong 2 project in the Republic of Korea, where a three-stage based modularization(weight 197 t, diameter 44 m, height 9.14 m) of these components was adopted. With this method, except for the first two stages, the remaining rings are modularized into three-ring sections and installed with one lift, thereby reducing the number of lifts and shortening the overall plant construction time. This modularization resulted in completion of construction in nine months as compared to the 11.5 months taken earlier using conventional methods. This method also simplifies connections with auxiliary buildings, since connecting provisions have already been attached to the ring modules, such as penetration sleeves for piping and electrical wire. The Manitowoc M-1200 ringer crane (main boom 115.2 m, work radius 52 m, capacity 238.4 t) being used to lift the 197t containment shell liner module of Shin-Wolsong 2 into place in the reactor building. [4]

Fig. 4. Modularization of the containment liner plate assembly, Shin-wolsong 2

*3.3. Steel Plate Reinforced Structure*

Steel plate reinforced concrete structure is applied as an alternative to the conventional reinforced concrete structure for the purpose of reduction in construction schedule and man-hours at the job site.

This method of erecting reinforced concrete structures was first used in 2002 in the construction of an auxiliary building(the incinerator building) at the Kashiwazaki-Kariwa 6 and 7 nuclear power plant site in Japan.

Steel-plate reinforced concrete construction(SC) methods offer significant schedule advantages compared with conventional reinforced concrete construction. The construction schedule is shortened because placement of rebar and removal of formwork are eliminated by the steel plate method. Since the steel-plate structure is designed to be self-supporting, it is possible to fabricate the reinforced concrete sections as modules off-site, transport them as a unit to be placed on-site, and welded together. Specifically, SC reinforced concrete construction method reduces the on-site work man-days by about 25%, as shown in Figure 5. This corresponds to a reduced cost in labor. [5]


Fig. 5. Comparison of the on-site man power requirement

But, Steel plate reinforced concrete structure requires early engineering. Embedded items need installing at steel plate prefabrication shop and request for cutting holes on the plate.

*3.4. All Whether Construction*

All weather construction method has been developed against the winter climate such as heavy snowfall, seasonal high wind, and low temperature. It is equipped with a temporary or structural steel frame covered with a tent and movable temporary roofs for the open top construction.

The all-weather construction method was used in Japan at Kashiwazaki-Kariwa Unit No. 6 for the reactor building and at Higashidori Tohoku Electric Power Co. Unit No. 1 for the reactor building, the turbine building and the auxiliary building. In this method, the side of the building is protected by a tent attached to the steel frame. Either temporary or structural steel can be used, which is taken into account in the building structure design. A temporary roof on a steel framework covers the entire building. The roof over the containment in the reactor building should be fully movable to provide space for the steel liner module, piping modules and the heavy components inside the containment to be lifted by open top. The roof can be moved using a VHL crane located outside the building, or be transported on rails using motor/manual winch operation. The roof over the perimeter of the containment in the reactor building consists of temporary steel, such as deck steel plates that also can be moved when equipment is lifted with the VHL crane, using the open top method. [4]

All weather construction method provides "factory-like" environment which supports the construction during the winter, especially to secure the environment for welding, concrete pouring and curing, protection for equipment.

## 4. Conclusions and Recommendations

Constructional engineering is a kind of science that has a variety of disciplines including structure, geology, mechanical equipment and other fields. Thus, the development of constructional engineering is closely associated with experience from failure and application advanced construction method. The recent experience in nuclear power plants construction has shown that those improved methods are fully applicable and can help shorten the construction schedule.

The future of nuclear power plant construction seems to be more encouraged, even though it has many obstacles. The most important challenge could clearly be represented in the need to distribute nuclear power plants and make them available as possible to serve more and more countries and places, moreover, to contribute in protecting the environment from the danger of global warming and the decreasing of non-renewable sources of energy.

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