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Comparison of APR1400(Shin-Hanul 1,2) and AP1000(Vogtle 3,4) construction: What brought such big differences?

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1. Introduction

Cost competitiveness is one of the factors that nuclear power maintained its predominance against other energy sources, however, it is being challenged due to a significant increase in construction cost [1]. Since the late 1950s when commercial nuclear power plants first appeared, construction costs have been on the rise, except for a few special cases such as South Korea [2]. This upward trend is attributed to factors like inflation, the rise of labor costs, material demand from stricter regulations, and indirect costs [3].

Recent research has specifically emphasized the substantial role of indirect costs in the overall increase in nuclear power plant construction expenses. Indirect cost includes items such as engineering cost and home office housing cost and is closely correlated with construction time since indirect cost escalates as construction gets delayed. Vogtle 3 and 4, the most recently built nuclear plant in the United States, suffered from significant delay and cost escalation despite efforts to employ innovative technologies such as modular construction to expedite construction and reduce costs. Meanwhile, South Korea has been building nuclear plants in affordable time and budget. This highlights potential issues within the construction process, leading to a detailed examination.

In such context, this study aims to investigate the challenges encountered in the application of best construction practices during the construction phase. A meticulous breakdown and a direct, apples-to-apples comparison analysis of the construction processes was carried on for the first time. Furthermore, this study also presents a key strategy to reduce the construction period for both designs with hypothetical scenarios: APR1400 and AP1000.

2. Construction Database of AP1000 and APR1400

2.1. DATA Acquisition

Records of construction-related activities were mainly collected from periodic reports issued by utility companies and regulatory agencies. Vogtle Construction Monitoring (VCM) semi-annual report [4] and Monthly Construction Report (MCR) [5] provide construction work with actual dates that occurred within a reporting period. They also come with a Gantt chart, which shows the overall work schedule with hierarchy. These reports are available at the Public Service Commission of State of Georgia. ITACC (Inspections, Tests, Analyses, and Acceptance Criteria)-related construction activities were obtained from the Quarterly Integrated Inspection Report (IIS) [6], issued by the U.S. Nuclear Regulatory Commission (U.S. NRC). Total 768 construction activities were obtained.

Since construction-related activities of Korean nuclear power plants are not open to the public, data equivalent to the collected Vogtle 3 and 4 construction data was provided by the Nuclear Power Plant Construction Department of Korea Hydro & Nuclear Power (KHNP) Co., Ltd.

2.2. DATA Classification

Collected construction activity data cover most of the construction process starting from procurement, component fabrication and delivery, concrete pour, MEP (Mechanical, Electronic, and Plumbing) installation, and licensing-related activities including initial testing. Afterward, these data were then systematically classified over six criteria: ①Naming, ②Safety classification, ③ System classification, ④ Elevation, ⑤ Component classification, and ⑥ Status classification.

These six criteria for classification were employed in the Database, making collected data easily accessible so that they can be utilized effectively throughout this study. The first four classifications employ standards and nomenclature of the Design Control Document (DCD) [6] for both AP1000 and APR1400. Full sets of documents are available in the U.S. NRC website.

Component classification system helps us sort out different parts by considering factors such as location, what materials they're made of, and their structure types such as Steel-Plate Reinforced Concrete(SC) or Reinforced Concrete(RC). This classification system provides a detailed understanding of the characteristics of each component and is presented in **Fig.1**.

In addition, Status classification system tracks the progress of each component over time. This includes stages such as fabrication, delivery, installation, and construction. This approach offers a clear and structured method for managing and understanding the details of construction components with respect to time throughout the whole construction phase.

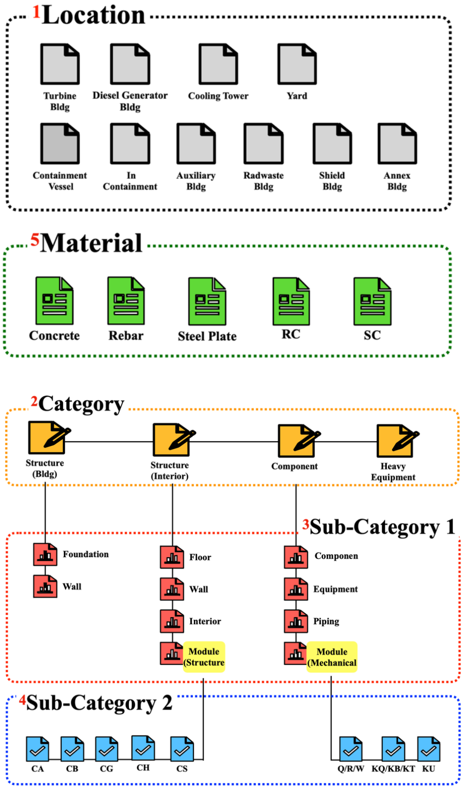


Fig. 1. Component Classification System

3. Methodology

3.1. Flowchart Plot

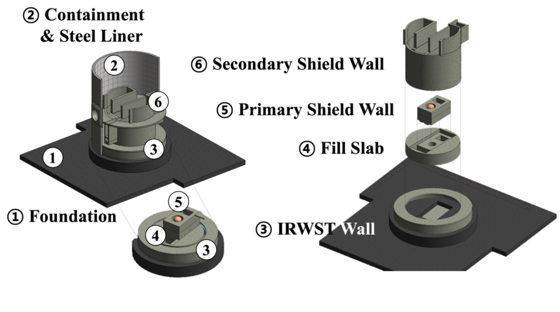
Gantt chart is one of the most widely used methods representing and furthermore managing construction schedules. Construction activities in Gantt charts are expressed in a bar graph which indicates the start and finish dates of the construction works. However, due to its static nature that only progress at a certain timeframe can be expressed, it has limitations in illustrating the whole construction process over time.

Under such circumstances, a new visualization method that presents height information over time was developed. Since construction typically proceeds sequentially from lower to higher elevations, such sequential progression has the inherent advantage of enabling the evaluation of the overall progress of construction by incorporating height information. In the context of concrete structures, it is a common practice to designate the final elevation achieved by construction activities, whereas for MEP components and equipment, the marked elevation corresponds to the floor of their installation. This approach is rooted in the sequential nature of construction processes, where structural work precedes equipment installation and subsequent placement of MEP components. The rationale behind this practice is to maintain a direct hierarchical representation within the visual plot, aligning with the chronological order of construction activities.

3.2. Building Information Management (BIM)

Building Information Modeling (BIM) is a digital representation and management methodology that integrates three-dimensional CAD model and relevant data such as materials, costs, and scheduling.

In this study, BIM models of Shin-Hanul 1 (APR1400) and Vogtle 3(AP1000) were developed. 3D CAD models adhered to the design specifications outlined in the U.S. NRC Design Control Documents, with supplementary data subsequently incorporated from reliable sources such as patents and official press-released materials. **Fig.2** is a BIM model of APR1400.



(a) APR1400

Fig. 2. BIM Model of APR1400
(IRWST – In-containment Refueling Water Storage Tank)

4. Results

4.1. Notable differences between APR1400 and AP1000

4.1.1. Modular construction and SC concrete

Modular construction is a method characterized by the pre-fabrication of building components or modules in a controlled off-site environment. These modules are then transported to the construction site for assembly into a complete structure. The process involves standardized designing and manufacturing units that can be easily transported and assembled, offering advantages such as increased efficiency, reduced construction time, cost savings, and enhanced quality control.

AP1000 reactor was designed for modular construction, incorporating extensive prefabrication of components and structures in a factory setting. Notably, SC concrete (Steel-Plate Concrete) replaced some structural elements due to its compatibility with modular construction. **Fig.3** illustrates structures that are replaced with SC concrete.

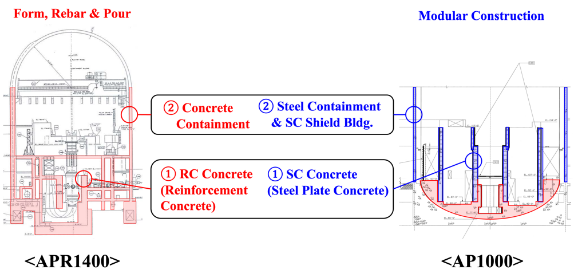


Fig. 3. RC and SC structures in APR1400 and AP1000

External cylindrical-shaped building and major In-CV (In-containment vessel) concrete wall structures supporting main equipment were replaced. The suitability of SC concrete (Steel-plate Concrete) for modular construction lies in its capacity for simple module placement – free-fabricated modules of two plates facing each other can be easily located by simply lifting them. Such attribute contrasts with RC (Reinforced Concrete) concrete, which poses challenges in lifting due to its weight and lack of modular flexibility. Modular construction utilizing SC concrete structures was also introduced as one of the innovative construction methods by the IAEA.

4.1.2. Open Top Method

Open-top construction method involves erecting structures without a conventional roof during specific construction phases, providing unlimited vertical access to the interior. This technique is particularly advantageous for installing large or heavy components. Notably, with this method, pre-fabricated modules can be easily placed using an external crane. This approach was employed in the Vogtle nuclear plant construction project. **Fig.4**. is a photo of the CA-01 module being installed in the containment vessel of Vogtle 3.

(a)

(b)

Fig. 4. (a) Installation of CA-01 Module using the external crane, and (b) after installation [4]

4.2. Flowline Chart

Fig.5 illustrates the flowline chart of Shin-Hanul 1(APR1400) and Vogtle 3 (AP1000). Comparison between two cases unveils notable insights.

Firstly, the construction of In-containment (In-CV) structural concrete poses a significant time-delaying factor for AP1000. The slope can be characterized by a gradual incline, with a substantial time delay of approximately four years from the first foundation concrete to reaching ground level— a prerequisite for commencing cylindrical wall construction.

In contrast, the construction of structural elements in APR1400 was clearly not a delaying factor. Most of the construction, including installation, was accomplished within three years. Unlike AP1000, where construction spanned almost eight and a half years, APR1400 adeptly managed construction works. BIM results also support that the concrete installation rate of APR1400 was greater than AP1000. **Fig.6** shows the concrete installation rate of APR1400 and AP1000.

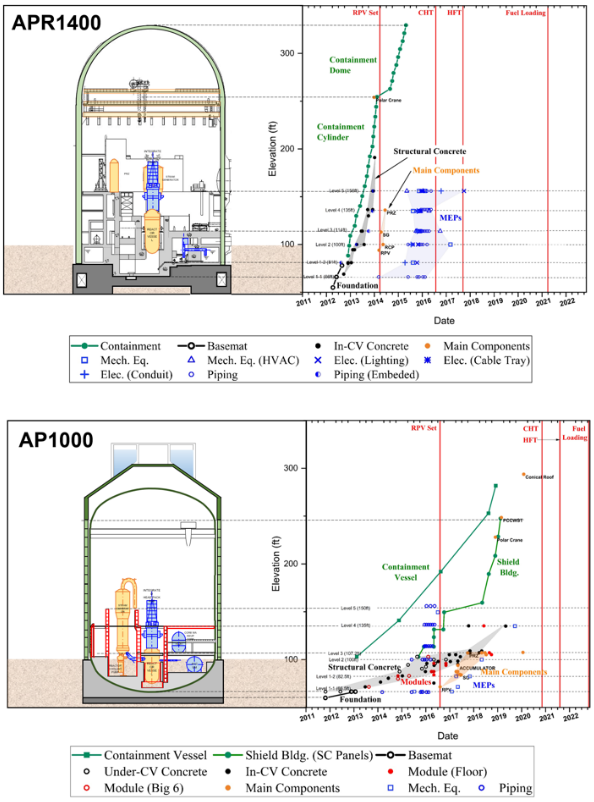


Fig.5. Flowline chart of APR1400 (Shin-Hanul 1) and AP1000 (Vogtle 3)

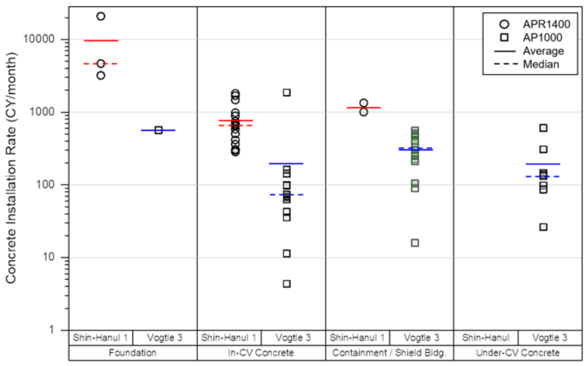


Fig.6. Concrete installation rate of APR1400 and AP1000

However, MEP installation emerged as a clear delaying factor in APR1400, extending beyond three years after the completion of structural elements and the installation of the reactor pressure vessel.

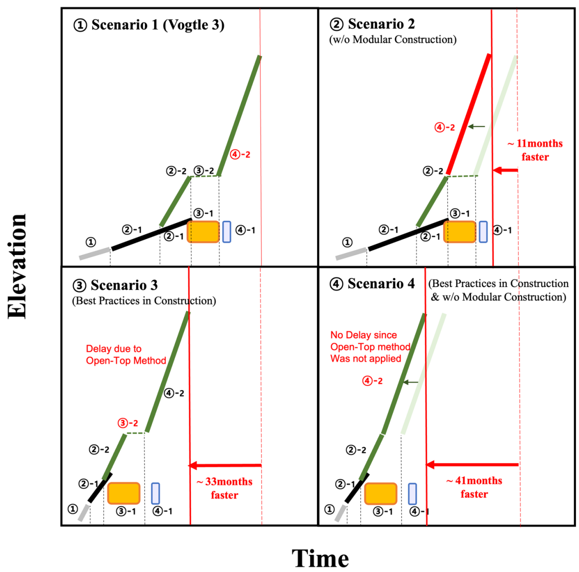
Despite exhibiting relatively inefficient and poor performance during the construction phase, AP1000 underwent shorter testing and licensing procedures compared to APR1400. Red vertical lines in Figure 5. denote major milestones. Most of the testing, turnover, and licensing activities occurred between Cold Hydrostatic Test (CHT) and Fuel Loading. The period between CHT and Fuel loading for AP1000 was shorter than that for APR1400. It may seem unfair to compare the two, considering Shin-Hanul faced critical licensing issues related to the Passive Auto-catalytic Recombiner (PAR) device during licensing and nuclear phase-out policy which delayed the overall process, however, it can be acknowledged that the U.S. demonstrated relatively effective practices in post-construction stages, encompassing testing, turnover, and licensing steps even during COVID-19 incident that lasted from 2020 to 2021.

4.3. Hypothetical Scenarios

Building on our earlier discussion, we determined that the competitiveness in constructing nuclear plants is closely tied to the effective implementation of best practices in concrete construction work. Given that the construction productivity of concrete for the AP1000 reactor showed lower figures compared to the APR1400, it suggests that there is room for improvement in the construction process of the AP1000 reactor.

Additionally, the adoption of modular construction methods, while offering advantages, has introduced various direct and indirect delays, particularly in the delays between constructing upper and lower shield buildings. These aspects should be carefully reconsidered for enhanced scheduling.

In such context, hypothetical scenarios based on Vogtle 3 construction case were developed. These cases include construction with and without the use of modular construction and assuming the concrete construction productivity of Korea. **Fig.7.** illustrates the construction processes for four scenarios: 1) Base Scenario (Vogtle 3) 2) Vogtle 3 not employing modular construction and open top construction 3) Vogtle 3 employing South Korea's concrete construction ability (installation rate) 4) Vogtle 3 not employing modular construction while employing South Korea's concrete construction ability.



① Foundation

②-1: In-CV concrete work
②-2: Shield Bldg. (lower half)

③-1: Installation of main components
③-2: Delay due to installation of main components

④-1: MEP installation
④-2: Shield Bldg. (upper half)

Fig.7. Hypothetical scenarios of AP1000 construction

All four exhibited a reduction in construction time. Scenario 1 demonstrated that nearly 11 months of construction time could be saved simply by making Shield Building work and In-CV work independent. Dramatic reductions were observed in scenarios 2 and 3 when applying high concrete construction productivity. These results indicate that the AP1000 design is not inherently impractical for construction.

5. Conclusion

This paper analyzed and compared the construction activities of AP1000 and APR1400 nuclear reactors, focusing on notable differences in design and construction processes. First, a flowline chart comparison between Shin-Hanul 1 (APR1400) and Vogtle 3 (AP1000) revealed that AP1000 faced significant delays primarily due to the slow In-CV structural concrete work. Moreover, additional delays were incurred due to the open-top method, resulting in a prolonged timeline for cylindrical wall construction.

Hypothetical scenarios showed the potential of collaboration between the U.S. and the Korean nuclear industry sector. By leveraging the high construction productivity of Korea, the U.S. nuclear reactors including AP1000 have the potential to revive their competitiveness in the nuclear industry by significantly reducing construction time and, consequently construction costs.

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