THE COMBINATION OF MODULAR AND COMPOSITE CONSTRUCTION TECHNOLOGY IN GENERATION III NPP DESIGN-BUILD

(1: General Perspectives and Constructability)

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ABSTRACT
As we are aware of that nuclear power plant (NPP) construction in 21st century is experiencing challenges on new technology application, cost reduction, resources management and scheduling assurance etc. If we look at the all new GEN III reactors construction (such as AP1000, EPR etc.), you will find that apart from new equipments/systems design - manufacture, the GEN III plants construction are facing many challenges, this is one of the reasons that GEN III reactors cost too much. So to solve this issue and advance construction, it is urgent to do more studies and especially summarize the successful experiences and lessons-learned from current GEN III reactors construction. This is important mainly because construction is the critical phase in which we can ensure the safety and quality and cut the cost to a reasonable range. This will give GEN III Nuclear Power good initiatives, privileges in current power industry.

Composite construction, as a very mature technology, has been using for many years in types of commercial structures. Modular construction due to its simplicity high quality and economic consideration already start to gain more applications in safety-related facility construction. The combination of modular and composite construction can create a better technology for nuclear power plant constructions, especially for generation III plant. This paper is focusing on the research of combination and application of these two construction technologies, and will give summary on the latest research results.

THE EMERGING AND DEVELOPING OF MODULAR CONSTRUCTION IN LARGE NPP PROJECTS
Steel concrete composite wall (SC-Wall), as a new emerged lateral load bearing structural type, is introduced as a new construction technique in recent decades to substitute the RC wall in some GEN III NPP design-construction to satisfy new safety requirements and reduces the cost as well. As an advancement of conventional composite structure (precast & composite, decking steel floor system), SC-Wall is comprised of two face-plates on both sides, concrete as infill is poured in between, and hardened to become a “sandwich” type component. The advantages of using SC-Wall come from the fact that the construction is simplified, faster and can be executed in a way of modularization. This greatly save on-site works and total construction time; also through the way of using workshop manufacturing and installation it can resulting in high quality of structural components.
The Early Application of Modular Construction in NPP Projects

Developed from precast technology, modular construction method is obtaining more and more application in new NPP constructions. Refer to its development and history, the early stage applications of modular construction were used in the NPPs’ construction in Japan. Following figures showed the types and approaches which were utilized in new plants construction in late 1990s and early part of 21st century in Japan.

Figure 1: Large size floor / roof modules

Figure 2: Internal SC structural modules

Figure 3: Steel frame modules

Figure 1 shows the method how to arrange small steel reinforcement cage and floor / roof components into large modules, and then lift the whole module to fulfil the installation processes. Figure 2 illustrates the new construction method developed for nuclear island (NI) containment internal structure (CIS) constructions. Generally the CIS are located in an internal environment where equipments, systems and structural components are all come together to perform their designated design functions. Figure 3 demonstrates the effective ways for steel constructions where all steel members / components are pre-assembled into large frame modules, and then lifted up as a whole to complete the installations.
The Employment of Modular Approach in AP1000 Design and Construction

AP1000 as GEN III technology, its innovation not only represented by the greatly optimized-simplified systems and components, but also through the concept of modularization which is utilized in both design and construction processes. With the completely re-designed structure-system-component (SSCs), the construction and installation process are improved in a manner that the SSCs can be built in parallel or alternative ways. Whereas the old construction approach tends to complete all primary structures first, and then commences the installation of major equipment system and component. This new concept of modularization can greatly simplified the on-site construction processes, improved quality and shortened the construction time. By putting all these advantages together, the cost for building GEN III reactor could be reduced. Figure 4 illustrates the AP/CAP plant SSCs construction processes based on the concept of modularization.

Figure 4: Modularization process for AP/CAP plant design-construction

Figure 5 and Figure 6 showed how this method is used in the constructions of containment internal structures and the containment systems, which rigorously speaking shall include steel containment vessel (SCV) and shield building.

Figure 5: Constructions of containment internal structures

Figure 6: Constructions of the containment system (shield building)
THE APPLICATION OF PRECAST CONCRETE COMPOSITE STRUCTURES

Precast concrete composite construction and structures are based on the precast concrete assembling structure type used in later half of 20th century. Precast composite structures are comprised of precast parts (or units), this will be assembled firstly in early construction phase to serve as formworks; then commercial concrete be poured above precast parts to designed thickness; rebars at jointing points or layers will be specially treated to assure they can perform in the similar way as to full cast-in-place case.

The Advantages of Precast and Cast-in-Place Composite Design

The advantages of precast composite structures can be summarized as following: (1) it eliminates the complicated and time consuming formworks at the site; (2) precast parts manufactured by the shop can improve the quality of structural members; (3) the inducing of pre-stressing force on precast part can effectively control the cracking and deflection of structure; (4) precast composite construction possesses both the features which full cast-in-place construction and full precast & assembled construction and thus is highly recommended for the applications in nuclear structures.

The Types of Structural Configuration and Utilization in NPP Projects

Following Figure 7 & 8 showed some of the precast composite construction application in NPP projects.

THE APPLICATION OF STEEL-DECKING CONCRETE COMPOSITE SLAB SYSTEM

The Popularity of Steel-Decking Concrete in Commercial Industry

Besides precast concrete composite structure, decking steel concrete composite floor system is another type of composite construction method widely used in commercial building structures. Figure 9 and 10 showed the shop manufactured decking steel unit types and the typical decking steel composite sections.
The Advantages of Applying Steel-Decking Concrete Composite Slab System in NPP Design-Build

Compared to precast composite, decking steel composite members possesses some unique features and advantages when applied properly in structural floor system design and constructions, which can be summarized as following: (1) Decking steel units are very easy to manufacture and transport; (2) it is easy to cut and re-arranged to fit the construction change; (3) it is easy to be installed at the place, in many cases, there is no need to use heavy lifting crane; (4) almost no need for any supports, it can be welded or bolted to the right place before construct the upper concrete layer. But on the other hand, decking steels also have some disadvantages which in some cases limit its application. Such as to illuminate construction supports the unit spans oftentimes are strictly limited to assure there will be no excessive deflection occurred before concrete develops any strength. This will limit its application in some large span structures unless mid-span supports are provided. So in some new NPPs’ construction, decking steels are frequently used for some small/medium span buildings with relatively high floor height.

THE RECOMMENDATION OF COMBINATION OF MODULAR AND COMPOSITE CONSTRUCTION APPROACH

The Challenges of GEN III Plant Design-Build in 21st Century

As stated in the beginning of this paper, nuclear power plant (NPP) construction in 21st century is experiencing challenges on new technology application, cost reduction, resources management and scheduling assurance. Follows are brief discussions on three most considered aspects:

(1) Management & Scheduling: The conventional NPP primary structures construction approach is based on on-site construction method (or called wet-construction). In this method almost all concrete works are done through a way of cast-in-place; that means the constructor will have to do basically the “formworks →reinforcement cage →cast of concrete”…and then next step of the same procedure; wet-construction here refers to the handling of fresh concrete. The advantage of this construction method is that it can guarantee the construction results highly reflecting the criteria that the engineer designed: such as the physical criteria of continuity and homogeneous, these are significant features required for assuring the structural integrity. Such method involves the handling and application of numerous loose materials members and components etc. the on-site construction management and scheduling are very complicated, trivial and time consuming.

(2) Quality & Cost: Based on the above analysis, the conventional construction method unavoidably cost many time (man-hours) and resources to satisfy the safety and quality requirements which were defined in the engineering documents. The human factor / errors and engineering changes could further result in problems / issues which oftentimes are the main reason lead to delays.
The Combination of Modular and Composite Construction

Composite construction, as a very mature technology, has been using for many years in types of commercial structures. Modular construction, due to its simplicity high quality and economic consideration, already start to gain some applications in safety-related facility construction. The combination of modular and composite construction can create a better technology for nuclear power plant constructions, especially for generation III plant.

The recommended ways for the combination of modular and composite construction

1. For lateral force resistance primary structures – “shear wall”
   For lateral force resistance primary structures, such as containment internal structure (CIS), steel containment vessel (SCV), shield building (SB) etc. it is recommended to utilize modular construction - such as steel concrete composite.

2. For vertical force bearing structural systems – “structural floor system”
   Vertical force bearing structural systems such as floor systems normally have large areas at different elevations. Based on their seismic design categories and structural features (e.g. span etc) precast composite and steel decking composite approaches are highly recommended.

3. For primary structures both considering lateral force and vertical force
   It is better to utilize the combination of modular method and precast /steel decking composite method to fulfil the construction processes. In reality, some CIS structures, auxiliary building can be classified in this category.

The construction feasibility study

Figure 2, 4, 5, 6 of this paper showed the kinds of detailed approaches which can be used to perform modular construction. Figure 7, 8 provided the configuration and details for precast composite construction method. Figure 1, 3, 9, 10, 11 and 12 illustrate the configuration detail and processes used for steel decking composite technique.

Figure 11: Steel decking floors for concrete structure
CONCLUSION
Based on the reviews of existing composite and modular construction technologies, new applications and
design-build methods are recommended for nuclear power plant construction, especially for AP and CAP
reactors, regarding of the design and constructions of CIS, SB and other safety-related structures within
nuclear island.

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Figure 12: Steel decking floors for steel frame structure