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The ACR®: Advanced Design Features for a Short Construction Schedule

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ABSTRACT

Through their worldwide operating records, CANDU® Nuclear Power Plants have repeatedly demonstrated safe, reliable and competitive performance. Atomic Energy of Canada Limited's (AECL) Advanced CANDU Reactor - the ACR® - is the genesis of a new generation of technologically advanced reactors founded on the CANDU reactor concept. The ACR is the next step in the evolution of the CANDU product line. The ACR products (ACR-700 and ACR-1000) are based on the proven CANDU technology and incorporate advanced design features and technologies.

Currently there are fourteen single unit CANDU 6 reactors operating or under construction worldwide. The first CANDU 6 reactors went into service in Canada and overseas in the early 1980s. The latest two units are at the Qinshan site in China. Prior to the Chinese units, construction had been relatively conventional. The project schedule for the first Chinese unit was 72 months with a 47 month construction period duration from First Concrete to Fuel Load. The first unit was completed 38 days ahead of schedule. Building on the successful CANDU construction at Qinshan, the ACR-700 is designed with constructability considerations as a major requirement during all project phases from the concept design stage to the detail design stage. A project schedule of 48 months has been developed for the nth ACR unit with a 36 months construction period from First Concrete to Fuel Load.

This paper describes some of the advanced design features implemented in the reactor building design in order to achieve this short construction period. These features include large volume concrete pours, prefabricated rebar, composite structures, prefabricated permanent formwork and significant modularization and prefabrication.

KEY WORDS: AECL, CANDU, ACR, nuclear, module, construction, constructability, parallel, prefabricate, construction, strategy, schedule, optimize, modularize, modularization.

INTRODUCTION

CANDU 6 reactors went into service in Canada and overseas in the early 1980s. Currently there are fourteen single unit CANDU 6 reactors operating or under construction worldwide. The latest two units are at the Qinshan (Phase III) site in China. Prior to the Chinese units, construction had been relatively conventional. For the Qinshan plant, advanced construction methods were implemented with minimum changes to the reference design. This resulted in a 72 month project schedule for the first Chinese unit with a 47 month construction period duration from First Concrete to Fuel Load. The first unit was completed 38 days ahead of schedule.

For the nuclear option to be competitive in the future, even shorter construction schedules are essential. Considering the construction method during the conceptual design stage of the project makes this possible. The ACR nuclear power plant is designed with constructability considerations as a major requirement during all project phases from the concept design stage to the detail design stage. An ACR construction strategy that utilizes advanced construction techniques has been developed based on the successful implementation of these methods in the Qinshan CANDU 6 plant in China (Reference 1). Continuing to develop these advanced construction techniques and applying them to the ACR design enables the construction schedule to be further reduced.

This paper reviews the ACR construction strategy and schedule and presents some of the advanced design features implemented in the reactor building design that will ensure achieving the ACR short construction schedule.

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PROJECT SCHEDULE

The major milestones considered in the project schedule are:

- Contract Effective Date (CED) refers to the date the contract is in place.
- First Concrete (FC) refers to the start of construction of the Reactor Building base slab. This requires a construction license from the regulatory body.
- Fuel Load (FL) refers to the activity of the first loading the fuel in the reactor.
- In-Service (I/S) refers to the in-service date for the unit.

Figure 1 illustrates the project schedule evolution for CANDU 6 plants and the schedule for the ACR-700 plant. As mentioned before, for Qinshan CANDU Unit 1, the construction period, FC to FL is 47 months with total project duration of 72 months. For an optimized CANDU 6 plant with more modularization and prefabrication, this construction period (FC to FL) can be further reduced to 42 months. Building on the Qinshan experience and further utilization of advanced construction methods, the ACR 1st unit construction period is 40 months, which can be further reduced to 36 months for the nth unit.

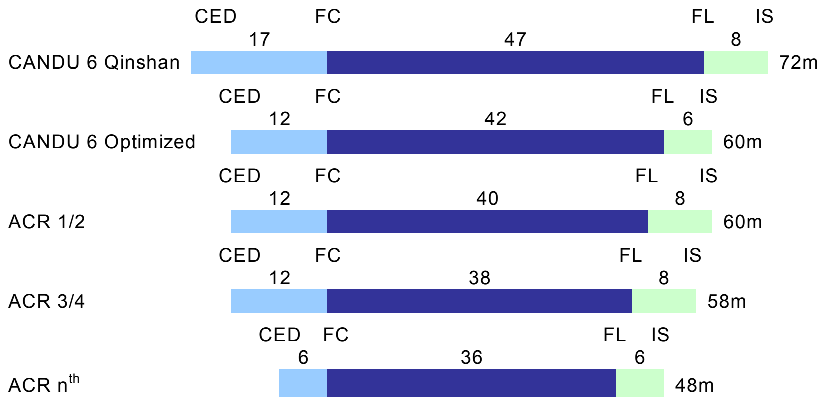


Figure 1 – Simplified Schedule Comparison

CONSTRUCTION STRATEGY

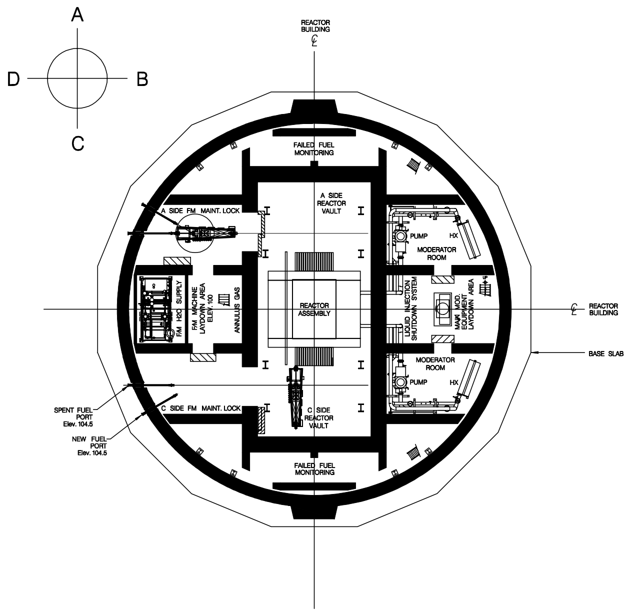
The reactor building consists of a steel-lined, pre-stressed concrete containment structure and a reinforced concrete internal structure supported on a reinforced concrete base slab. The containment structure provides an environmental boundary, biological shielding, and a pressure boundary in the event of a loss-of-coolant accident. It is the principal component of the containment system. A reactor building plan view and section view are shown in Figures 2 and 3, respectively.

The containment structure perimeter wall is separate from the internal structures. This provides flexibility in construction and eliminates any interdependence between the containment wall and the internal structures. The internal concrete structures include the reactor vault walls, the fuelling machine vault walls, the moderator enclosure walls, the steam generator enclosure walls, the heat transport pump support walls and floors, the reactivity mechanism floor, and intermediate floors. The internal structures also include some steel floors to provide equipment support, pipe restraints, walkways and stairs.

The construction strategy developed for the ACR reactor building comprises the following:

- “Open Top” construction technique using a Very Heavy Lift crane,
- Paralleling of construction activities,
- Extensive modularization and prefabrication, and
- Implementation of advanced construction technologies.

This construction strategy was successfully implemented in the CANDU 6 Qinshan project. The same strategy is adopted for the ACR-700. However, in order to meet a shorter schedule, it is necessary to increase the paralleling of construction activities, the level of modularization and prefabrication and the utilization of advanced construction technologies.



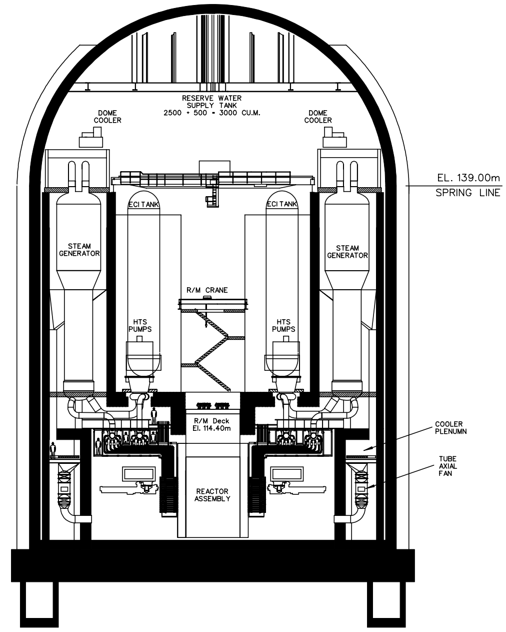


Figure 3 – Section View of Reactor Building

Figure 2 – Plan View of Reactor Building

MODULARIZATION

In order to achieve maximum utilization of paralleling of construction activities, the systems inside the reactor building are designed and built as modules. In this case, a large volume of mechanical/electrical work that is traditionally done on site is shifted out of the reactor building for fabrication into modules. Therefore, the mechanical/electrical work can be done in parallel with the civil program. To realize the maximum gain from modularization, as much equipment, piping, and interfacing systems are included in the modules prior to installation into the building. Generally, each room consists of a complete module. In most cases, the room floor is the main base for the module allowing inclusion of everything in the room as part of the module before installation into the building.

ADVANCED CONSTRUCTION TECHNOLOGIES

One of the major elements of the construction strategy is the use of advanced construction technologies in the design and construction of the ACR-700 (References 2, 3 and 4). These advanced construction technologies include:

- **Large Volume Pours** - With the development of low-heat concretes, large volume pours are practical and have major benefits. Pours up to 6 m deep will be utilized and vertical bulkheads minimized on areas such as base slab and the concrete internal structure major walls.
- **Prefabricated Rebar** - Rebar installation by individual bar placement is very time-consuming and produces long durations for critical path activities. For such areas as the base slab, containment walls and internal structural walls, rebar assemblies are designed for maximum prefabrication.
- **Use of Climbing Forms** - For improved schedule and precision of poured concrete, climbing forms will be used for both the reactor building containment and internal structure walls.
- **Use of Composite Structures** - The composite structures being considered are essentially large steel fabricated box sections that are later filled with concrete for compressive strength, shielding and seismic qualification. These structures, when combined into modules have the advantage of eliminating formwork and rebar.

- **Use of Prefabricated Permanent Formwork** - In conventional construction, equipment is installed after the completion of the floor above. This method is time consuming as no work at all, including installation of equipment can be done until all the shoring has been removed. In the case of heavy slabs, removal of shoring cannot be done before 7 days, preferably 14 days. In addition to the concrete curing duration, installation and removal of conventional shoring further impedes work in the room. In these areas it is more practical to design a bridging system (usually steel containing prefabricated rebar) that will span over the top of the room and will act as the formwork.
- **Use of Automatic Welding** - Greater use of automatic welding will lead to reduced durations for welding, improved weld quality and reduced weld repair. This will be applied to the steel containment liner and all piping systems particularly large size heavy wall piping.
- **3D CADDs** - (Computer Aided Design and Drafting) provides consistent, high quality output with minimal field interferences due to clash checking capabilities and therefore reduction/elimination of rework. In addition, 3D CADD has been developed to prepare construction sequences to match the schedule through links with scheduling software packages (4D visual models).

REACTOR BUILDING CONSTRUCTION METHOD

The construction method for the reactor building was established by evaluation of various options against the project requirements. Based on the evaluation, the vertical installation approach was chosen as the method of construction for the reactor building. This vertical installation approach is summarized below. A simplified construction sequence is shown in Appendix A.

- Reactor vault & internal structure walls all rise together using standardized climbing formwork, forming a honeycomb structure – conventional concrete & rebar construction. Initially no floors so jump forming proceeds quickly.
- The vault walls, a rectangular portion of the internal structure contains the reactor assembly at base slab elevation, are key to the center of the internal structure. Walls continuous from base slab to top of the internal structure.
- Remaining internal structure around vault divided into 12 vertical, roughly rectangular compartments with one curved side, which is the containment wall contour. Both containment and internal structure walls jump formed with reinforcing steel suitable for prefabrication. See Figure 4 shows the 12 major vertical installation compartments.
- All compartments filled with modules or equipment installed through the "open top" using heavy lift crane. Modules, which include floors, are attached to the internal structure walls but not the containment wall.
- Floors are part of the module and generally of steel beam construction. These floor modules will rest on brackets welded to embedments.
- In most cases the steel floor will directly become the skid base and it would be delivered to site as a unit. In other cases the skids and equipment can be delivered to site and installed on the steel floor prior to installation.
- Floors requiring concrete for shielding will be filled with concrete after installation of the module.
- Where monolithic floors are required to stiffen the overall internal structure, these will be added after the walls. Typical methods of connections to the internal structure walls are shown in the next section.
- Normally two to four levels of modules/equipment in each vertical installation compartment. During layout, standardized floor elevations developed for ease of movement between vertical installation compartments.
- Wiring and service connections are routed vertically to service each particular vertical installation compartment. Wiring will travel vertically up or down the vertical compartment and be connected to wall containment penetrations designed to serve the vertical compartment.
- Temporary weather covers will be installed on a compartment basis during the open top construction phase to provide dry working conditions.

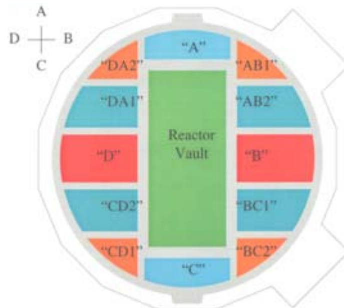


Figure 4 – Plan View of Reactor Building Vertical Installation Compartments

MODULE CONNECTIONS

From a structural point of view, there are several types of module connections to the internal structure. An example of a module located on the base slab (the lowest level of the reactor building) is illustrated in Figure 5, and it's installation sequence is provided in Figure 8. A typical example of modules supported from the building internal structure walls, not requiring concrete in the module base, is illustrated in Figure 6 and it's installation sequence is provided in Figure 9. A typical example of modules supported from the building internal structure walls, requiring concrete in the module base, is illustrated in Figure 7 and it's installation sequence is provided in Figure 10.

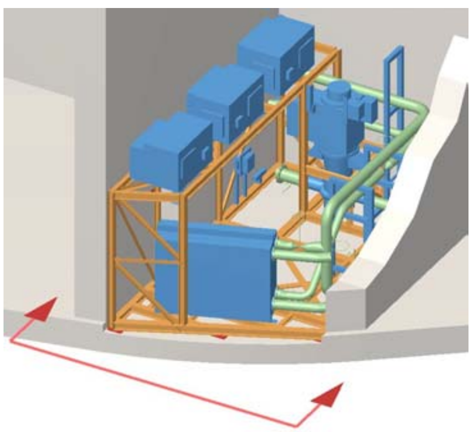


Figure 5 – Example of a Module on the Base Slab (see Figure 8 for installation sequence)

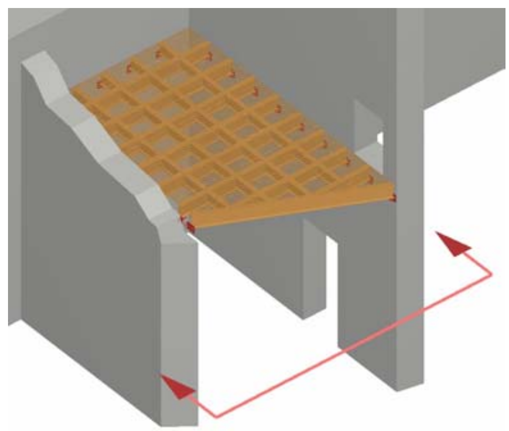


Figure 6 – Example of a Module Supported from Internal Structure (Not Requiring Concrete in Base) (see Figure 9 for installation sequence)

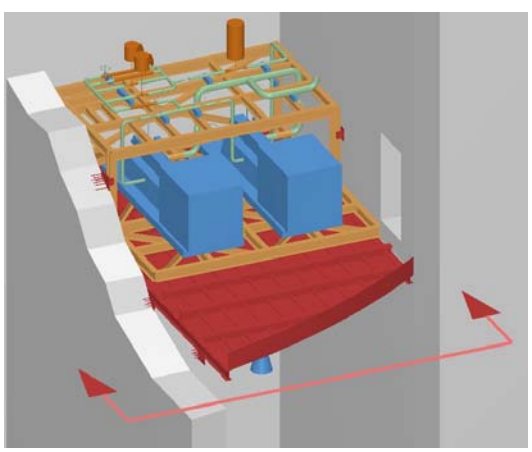
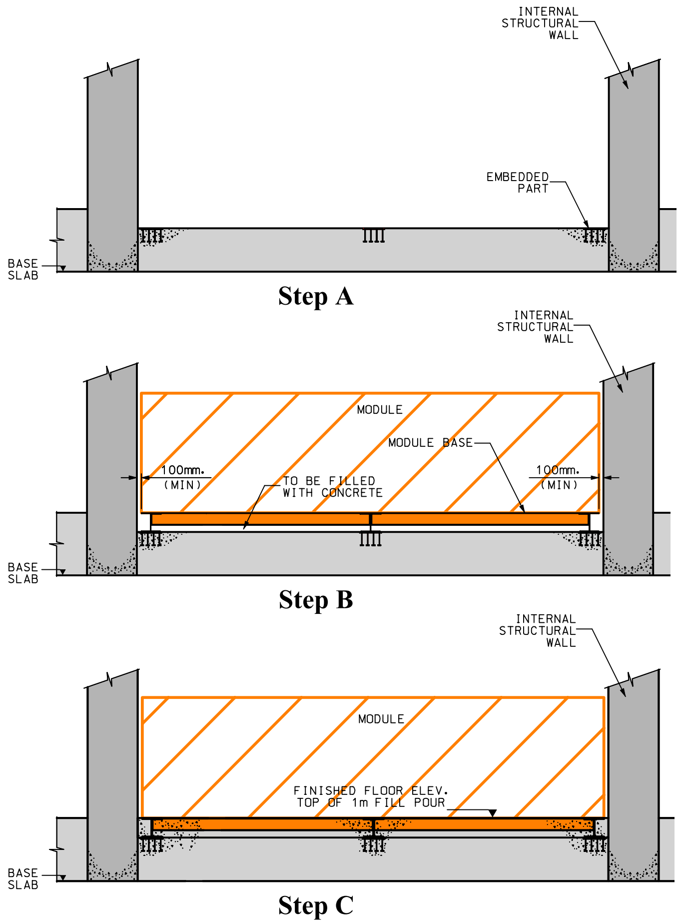


Figure 7 – Example of a Module Supported from Internal Structure (Requiring Concrete in Base) (see Figure 10 for installation sequence)

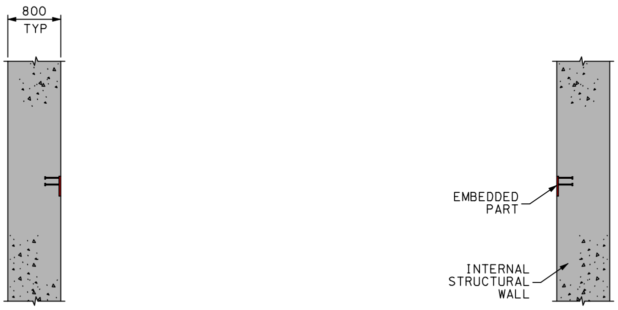


Step A: The base slab fill pour is not initially poured to the finished elevation in the areas where modules are located. Embedments are provided in the fill pour for connection to the module base.

Step B: The module is lowered vertically and placed on embedments in the recessed area of the base slab fill pour. The module base is shimmed to ensure the floor is flush with the adjacent floor. The module base is then welded to the embedment.

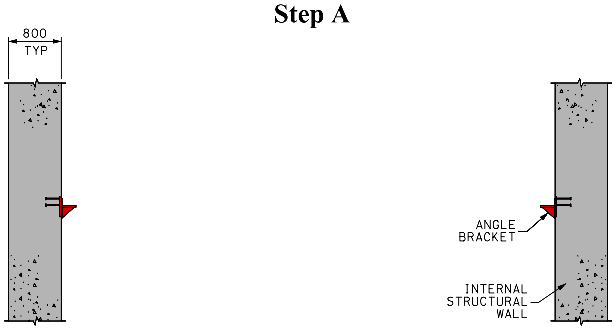
Step C: If required additional reinforcing is provided and then the recessed area in the fill pour is filled with concrete to be flush with the top of the module base. Additional anchors are provided to embedments in the walls for seismic bracing near the top of the module.

Figure 8 – Sequence for Installation of Module onto Base Slab (Lowest Level of Vertical Installation Compartment)



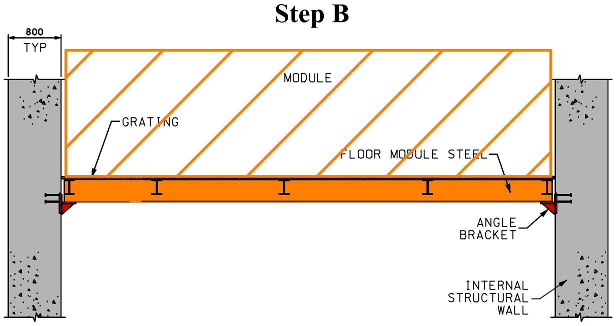
Step A

Step A: When the internal structure walls are jump formed, embedded parts are provided for angle support brackets.



Step B

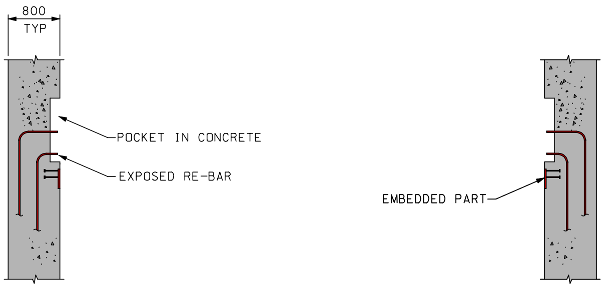
Step B: Angle support brackets are attached into the embedded parts.



Step C

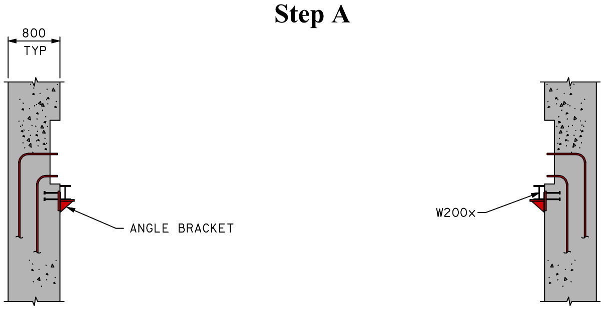
Step C: The module is set in place in the vertical installation compartment to the required elevation using shimming on the angle brackets.

Figure 9 – Sequence for Installation of a Steel Frame Floor Module into a Vertical Installation Compartment (Concrete not required in the floor)



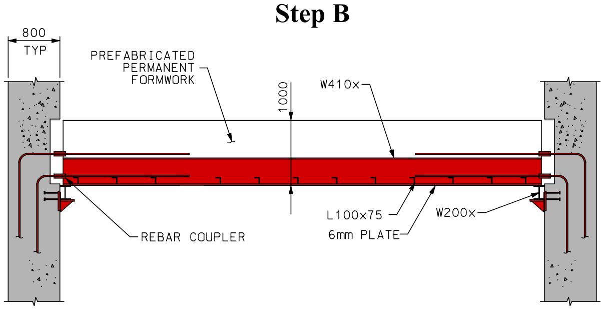
Step A

Step A: When the internal structure walls are jump formed, embedded parts are provided for angle support brackets and recesses are provided in the concrete for access to rebar connections.



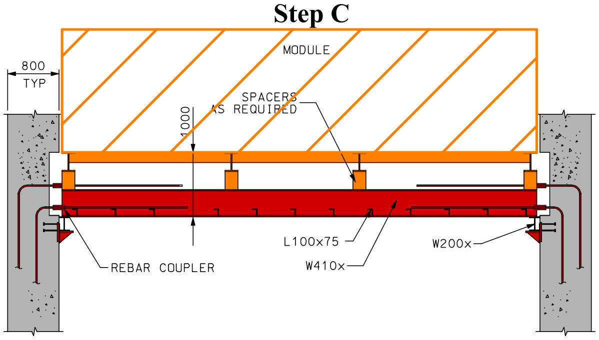
Step B

Step B: Angle support brackets are locked into the embedded parts ready to accept the prefabricated permanent formwork floor (PPF).



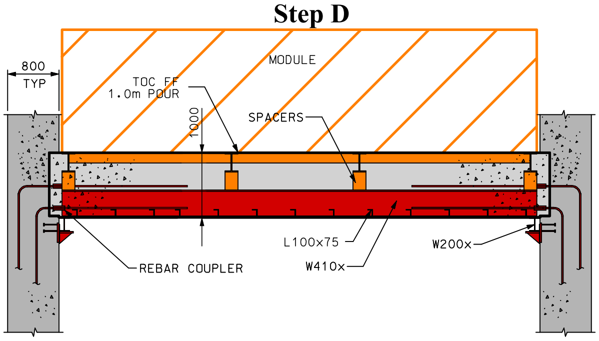
Step C

Step C: The PPF is installed vertically and placed on beams, supported by the angle support brackets. The beams distribute the load to the brackets and seal the PPF to the wall for later concreting. Reinforcing in the PPF is connected to the exposed reinforcing in the walls.



Step D

Step D: The module is lowered onto the PPF and set to elevation, spacers are provided to ensure the module floor is flush with the adjacent floors.



Step E

Step E: Concrete is poured to fill the PPF, recesses in wall and up to the top of the module base, flush with the adjacent floors. Additional anchors are provided to embedments in the walls for seismic bracing near the top of the module.

Figure 10 – Sequence for Installation of a Floor/Module into a Vertical Installation Compartment (Concrete required in floor for shielding or structural purposes)

CONCLUSIONS

The ACR-700 is designed using the latest construction methods to achieve a 36 month construction period for the nth replicated unit. A strategy has been developed based on the proven successful implementation in the Qinshan project. This strategy is further extended for implementation in the ACR project to achieve the shorter schedule and reduce project costs and improve quality. One of the key construction strategies that assist in achieving the short construction schedule is prefabrication and modularization. Using the vertical installation method, the modules are installed into the reactor building using the very heavy lift crane. Various connection details for attaching the modules to the internal structure walls were developed to illustrate the feasibility of the construction concept.

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Appendix A TYPICAL VERTICAL INSTALLATION COMPARTMENT CONSTRUCTION

(Reactor Building containment sectioned on all views and internal structure sectioned on last four views)

Construction sequence from month 4 to month 36 of the nth unit construction period.