Composite steel-concrete modular construction for new-generation nuclear power plant

Several manufacturers of third generation nuclear reactors have made composite steel-concrete (SC) modular construction (see Figure 1) an integral part of new nuclear power plants (NPP). In Japan, it was first used in a solid waste disposal incinerator building in Kashiwazaki-Kariwa NPP and shown to reduce labour requirements, shorten the construction period and improve construction safety and working conditions.

Tokyo Electric Power Company is using SC modular construction at Higashidori Unit 1 in the Boiling Water Reactor (BWR) NPP in a number of floor and wall modules as well as the turbine pedestal. SC modular construction is also proposed by Mitsubishi in their new generation of Pressure Water Reactors (PWR) and is used for the containment vessel of the next generation of BWRs devised by Hitachi. Another example is Westinghouse Electric Company’s AP1000, which uses modular construction in the slabs and walls of the auxiliary building, the containment internal module and parts of the shield building.

Modularisation using SC structural elements speeds up the construction process and reduces overall costs. In the initial construction stages, it shortens the critical path on site, allowing the plant to begin commercial operation sooner. However, whilst the cost and schedule benefits are well established, there is limited guidance on structural design of SC structures in national codes. This has led to uncertainty in design and delays and significant effort on the part of both designers and regulators during the licensing process.

Whilst there has been some design code development in Japan, South Korea and (more recently) the USA, in Europe — where there is a significant programme of nuclear new build — there is currently no code or guidance for the design of SC structures.

Against this background, SCI is leading a major project to develop European design rules for SC structures used in NPPs. The rules will follow the format of Eurocodes, whilst recognising the safety-critical nature of many of the structures used in NPPs. The project combines reliability analysis, testing and numerical studies and covers both the construction and in-service stages. The fundamental requirements of the IAEA (the International Atomic Energy Agency), which stipulates a deterministic design followed by a full probabilistic assessment to ascertain the level of notional failure probabilities for different performance levels, will be adopted.

A reference building is being used to highlight problem areas in existing design methods for concrete and composite structures when applied to SC construction, and to help define the detail of a series of test programmes dealing with four main areas:

- **Member behaviour**: large scale bending tests (9.0 metres span and 0.8 metres deep) to examine plate buckling and tensile failure, out-of-plane shear failure, horizontal shear failure and in-plane shear failure.
- **Connection behaviour**: T-shaped connection tests under a range of load scenarios and combinations.
- **Mechanical behaviour** under low temperature thermal strains: tests with combinations of thermal loading and mechanical loading (axial or bending or both) followed by bending tests after cooling. This is of interest in the context of the walls of spent fuel pools in NPPs in the event of heating up to 100°C of the water in the pool or a ‘loss of coolant accident’ (LOCA) leading to heating of the reactor building structure to 170°C.
- **Fire tests** under axial load.

Data generated will be complemented by numerical simulations using non-linear finite element (FE) analysis. Design rules will be prepared and tested through a re-design of the reference building chosen for the project. Comparisons will be drawn with alternative designs in reinforced concrete to illustrate the differences in programme, material usage and cost.

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