

## **CONSTRUCTION OF A STEEL-CONCRETE (SC) DEMONSTRATION BUILDING – SCHEDULE PROJECT**

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### **ABSTRACT**

Steel-concrete composite (SC) comprises two steel plates connected by a grid of tie bars and infilled with concrete. SC is an alternative to reinforced concrete (RC) for wall and floor elements with the added benefit of offsite prefabrication in modular form and the potential for significant savings on site.

In order to understand the manufacture and construction challenges of SC construction, a major European project (SCHEDULE Project) was undertaken. It entailed the construction at full-scale of a replica of the EDF diesel generator building (DUS). This enabled comparisons of manpower, time and material usage between SC and RC. Two corners of the building were dedicated to studying the construction of airplane crash (APC) shells (using thicker steel plates and wall construction) and spent fuel pools using hybrid SC modules with carbon steel and stainless steel plates and incorporating leak detection channels. This was a deviation from the standard DUS building design.

Records were kept during manufacture and construction of material usage, work hours and number of workers to enable a comparison with RC construction. Lessons have been learnt at all stages of the project which will lead to greater efficiency on future projects. The paper describes the project and highlights some lessons learnt in the modelling, the manufacturing and the module joining methods. Other papers in the conference cover the structural design and the construction.

### **INTRODUCTION**

A modular form of construction that has found appeal in the nuclear sector uses steel plates with shear studs acting compositely with concrete (Figure 1). A double skin steel concrete (DSC) composite is made of two steel plates connected by a grid of tie bars with concrete between the plates. Composite action between the steel plates and the concrete is provided by shear connectors welded to the steel plates. DSC structures are commonly used in a vertical orientation as walls but may be used in a horizontal orientation as floors. Single skin steel concrete composite (SSC) structures comprise a single steel plate reinforced by steel sections (typically T-stiffeners) which provide stiffness during construction and shear resistance to the section against out of plane loading in the permanent condition. Shear stud connectors are welded to the plate and the flange of the T-stiffeners to achieve composite action with the concrete which is placed on the plate. SSC structures are used in a horizontal orientation as floors.

The SCHEDULE Project studied at full scale the manufacture and construction of complex buildings in the nuclear sector using SC construction, to quantify the materials and effort involved and to compare the outcomes with reinforced concrete construction. To do this, a pilot building was constructed in SC as a replica of the reinforced concrete EDF ‘Diesel Ultime Secours (DUS)’. The DUS building is rectangular on plan (24.1 m x 12 m) and 14.84 m high (Figure 2). A total of 58 such buildings have been constructed and hence much data is available on construction times and costs in reinforced concrete.



Figure 1. SC structural forms

Two modifications were implemented at the top level of the pilot building that are not part of the RC DUS building (

Figure 3). The first was a structure with the performance requirements of a spent fuel pool in a nuclear power plant to assess the buildability of spent fuel pools (which require special detailing, leak tightness and Execution Class 4 for the internal plate). It had internal dimensions 5.30 m x 3.28 m x 2.20 m, stainless steel plates on all internal faces (except the roof), and leak tightness requirement with leak detection channels behind some site welds in the stainless steel plates.



Figure 2. The EDF Diesel Ultime Secours (DUS) building

The second modification was the introduction of thicker walls (1.3 m with 20 mm and 12 mm external and internal steel plates) representative of an APC shell. This was used to assess buildability and achievable weld execution quality of thick plates in DSC walls. For the remainder of the building, the overall thickness of the main structural elements was the same as in the RC DUS building. Hence, external and main wall thicknesses were 500 mm (with 8 mm steel plates), internal secondary walls were 300 mm (with 8 mm plates) and floors were 500 mm thick with 8 mm bottom plate and T-stiffeners at 0.8 m spacing.

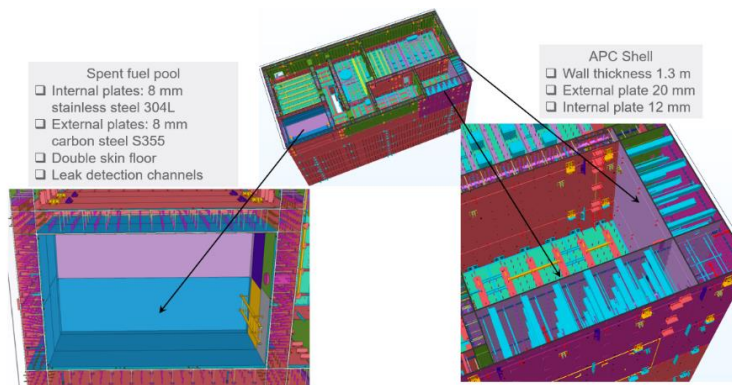


Figure 3. Position of the spent fuel pool and APC shell in the pilot building

## **BUILDING MODELLING**

Building information modelling (BIM) was used throughout the project. The model was developed in three stages: conceptual, basic and detailed design. At conceptual design stage the BIM was based on the DUS building supplemented by requirements for the APC shell and pool. It included volumes, main openings, wall and floor thicknesses, assumed steel plate thickness and an initial module layout. The basic design BIM included additional features based on the proposed site assembly methodology (e.g. module size, weight, erection methods, safety measures, connections between modules) and the proposed module manufacture methodology (e.g. maximum size of modules for manufacturing and transportation, welding methods, etc.). It also included the method of module joining on site, definition of the steel grades, accurate representation of the modules (plate thickness, studs, tie-bars, stiffeners) and final layout of the modules. The detailed design BIM included, in addition, all manufacturing details, reinforcement details, ancillary components used for handling the modules and for site assembly, weld specifications and module finishes.

BIM was found to be extremely useful for this form of construction in order to coordinate design, manufacture and construction and avoid clashes between different components and trades. However, the model was developed by the party responsible for engineering coordination and then passed on to the manufacturer. Greater efficiency would have resulted from having the model on a shared platform and developed to an agreed modelling specification.

The structural analysis of the building was performed using a 3D shell element finite element model. The actions and combinations of actions were similar to those used in the analysis of the RC DUS building. Additional analysis and design checks were performed for the construction stage, when modules behave non-compositely as a steel structure. Further detail of the analysis and design of the pilot building are given by Tuscher and Huguet (2024).

## **MODULAR FORM OF THE PILOT BUILDING**

Decisions about subdividing the building into modular units that can be assembled on site aim to balance physical size constraints, time and cost of fabrication, transportation and site assembly considerations. Methods of joining modules on site have an impact on the design of the structure, module manufacture and fabrication tolerances. The proposed construction methodology also has an impact on module design, particularly for the construction stage. The module layout chosen comprised 6 levels made up of a total of 158 modules (82 wall, 6 APC, 6 pool and 64 floor modules). The main factors taken into consideration in arriving at final module layout are summarized below and they demonstrate the importance of early involvement of the main contractor and manufacturer with the designer and the building owner.

### ***Building geometry***

In dividing the building into modules, it was ensured that horizontal wall-to-wall module joints were at a different level from wall-to-floor module joints to avoid congestion/clashes at joints. Small penetrations through walls and floors were contained within module wherever possible rather than split across modules.

### ***Manufacturing considerations***

The standard plate size available for manufacture was 2.5 m x 12 m. Therefore, larger modules would require plates to be butt welded with time and cost implication. There are also transport cost implications for taller modules. On the other hand, taller modules reduce the number of levels to be assembled and saves time on site. The balance struck between manufacturing and transportation effort and the number of levels to be assembled on site led to the first row of modules being 3.89 m high followed by five rows of modules each 2.4 m high (or less), hence a total of 6 levels of wall modules making up the full height of the building.

Maximum crane capacity in the factory for handling modules was another consideration and placed a limit of around 10 tonnes on maximum module weight. A further consideration was the maximum size of doors (4.0 m wide x 4.5 m high) for moving modules out of the factory. Finally, available storage space at the factory dictates the quantity of modules that can be prefabricated and stored ready for delivery to site. In SCHEDULE, around 1000 m<sup>2</sup> was available for factory module storage.

### ***Transportation considerations***

The maximum dimensions of modules to fit into a conventional trailer are 13.60 m length, 2.45 m width and 2.60 m height. Larger modules can be transported using special trailers (e.g. inloaders) which can transport modules with maximum length of 9.80 m with the top of the module no more than 4.50 m above road level due to clearance under road bridges. However, inloaders incur a cost penalty relative to conventional trailers. In SCHEDULE, transporting the modules to site required 30 standard trucks and 9 oversize trucks.

### ***Site assembly considerations***

The main requirements for site assembly were to minimize the quantity of site joints and to keep the joints as simple as possible. This meant maximizing the module sizes (within the manufacturing and transport limits) and led to ensuring that all site vertical joints between modules were planar (hence any orthogonal joints were integrated into the modules in the factory). This led to a number of modules being L-shape, T-shape or TT-shape and this had an impact on manufacturing effort.

### ***Pool modules***

The pool modules were the most complex as (i) both the walls and the floors had to be double skin (DSC) so as to have a watertight barrier on the wet side; (ii) the modules were hybrid with stainless steel plates on the wet side and carbon steel plates on the dry side; (iii) the site joints between modules had to be butt welded and therefore required strict tolerances and (iv) a leak detection channel had to be incorporated at site welded joints. The pool structure was divided into 6 modules, two for the pool floor and four for the walls as shown in Figure 4.

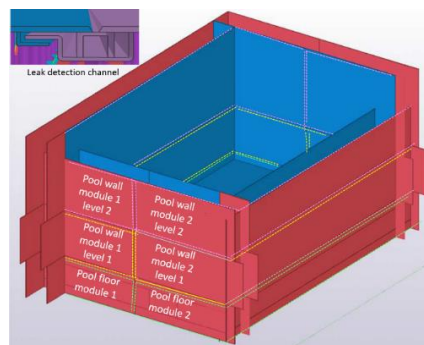


Figure 4. Pool modules and leak detection channel

### ***Module joints***

Different types of wall to wall module site joints were used to evaluate their relative merits. The first four levels of wall modules were mechanically joined using embedded dowel bars at both their vertical and horizontal joints. In this type of connection, a series of dowel bars placed across the joint between modules provides the mechanical connection once the modules have been concreted. Modules in levels 5 and 6 were

either fillet or butt welded. One wall module at level 5 was joined at both its vertical edges using the Holo-Bolt<sup>®</sup> system. The floor modules were bolted to the wall modules using double angle cleats. The different types of joints and their location in the pilot building are shown in Figure 5.

## MODULE MANUFACTURE

### *Manufacturing tolerances*

A comprehensive set of tolerances was defined early in the project. These covered both local module geometry (e.g. position of tie bars within modules, separation between module plates, plate flatness between tie bars) and global module geometry (e.g. module size, overall module straightness, ‘squareness’ of corner modules) and were in addition to EN1090-2 (2018) requirements (which gives tolerances for plated construction). This attention to tolerances early in the project paid off, as modules were manufactured to a high degree of accuracy. Compliance with tolerance specifications was verified by manual measurement and, for some modules, also by laser scanning.

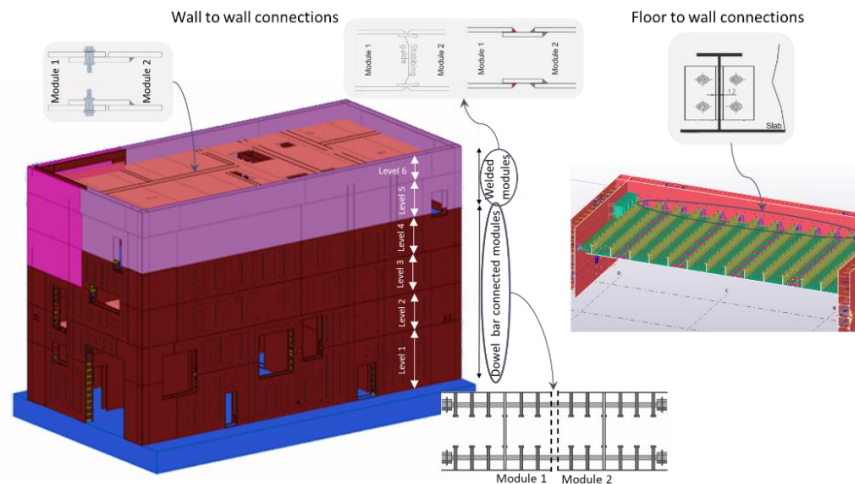


Figure 5. Types of module-to-module joints

### *Method of manufacture*

The basic materials used in the manufacturing of the modules were 8 mm S355 carbon steel plates, 19 mm diameter shear studs and 20 mm diameter tie bars. A number of other components were used either to stiffen the modules (short internal stiffeners) or for the attachment of other members or ancillary components (e.g. couplers, threaded studs). The simplest modules were planar (two dimensional) and their manufacturing and assembly sequence is as shown in Figure 6; it comprises the following steps:

- Drilling holes in the plates for the tie bars and slots in one of the plates for stiffeners.
- Welding of shear studs to each plate.
- Fillet welding stiffeners to the inside face of one of the plates.
- Bringing the two plates together.
- Joining the two plates together by butt welding the stiffeners to the second plate from the outer side through the pre-cut slots.
- Inserting the tie bars through the pre-drilled holes in the two plates and butt welding one end of the tie bar to the plate from one side and then turning the module over and butt welding the other end of the tie bar to the plate.

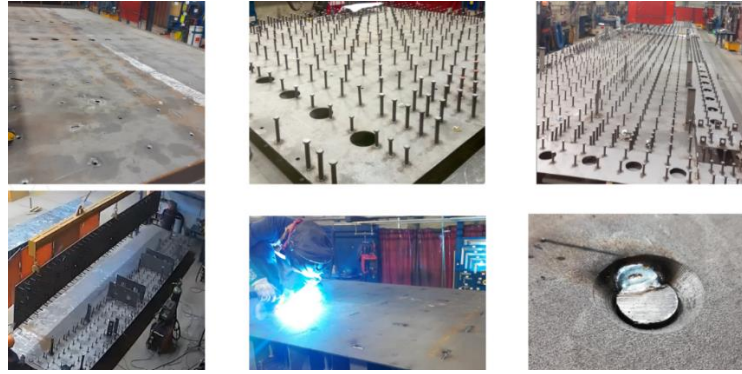


Figure 6. Planar module manufacturing sequence

***Other module features***

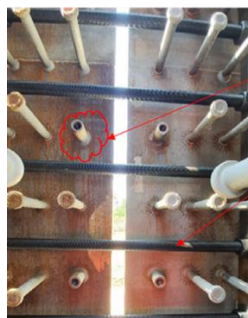
Modules also included a number of other features which were necessary, either for compliance with the structural design assumptions or for the construction stage (Figure 7). Examples include couplers and headed bars in the wall modules for anchoring of floor slab reinforcement, couplers used for removable tie bars at the edges of modules joined by the dowel bar connection, nuts for bolting floor module angle cleats to the walls, brackets for supporting the dowel bars, lifting plates for module handling and threaded studs on the outer surface of wall plates for supporting the range of ancillary components used in the construction stage see section on “Ancillary components”).



Coupler and anchor for rebar



Support bracket for dowel bar



Couplers for removable tie bars



Nuts for bolting floor angle cleats



Module lifting plate



Threaded studs for ancillary components

Figure 7. Examples of components incorporated into the modules during manufacture

### *Ancillary components*

The construction methodology called for a number of temporary ancillary components to be used in the site assembly of the modules. They included “hard stops” which will be fixed to the concrete raft to facilitate the installation of the wall modules at the first level, levelling jacks to ensure each module is both level and at the correct height, vertical installation guides to facilitate the installation of an upper module onto a lower module, brackets for stabilisation props to support the modules in storage on site and after installation but prior to concrete setting, angles to provide temporary connection between modules and attachments to support the working platform on the wall modules. Examples are shown in Figure 8.



Hard stop



Bracket for stabilisation



Temporary connection



Levelling jacks



Vertical installation guides



Support to working platform

Figure 8. Temporary ancillary components used for construction

### *Manufacturing efficiency*

Several techniques were developed during the project to improve efficiency of manufacture. These included the use of scribing (pre-programmed into the BIM) during plasma cutting to mark the positions of studs and other small components that were to be welded, the use of special lifting frames, the use of specially developed tools to maintain accurate spacing between the module plates and the use of intermittent rather than continuous welds where justified by structural verification.

The total number of hours spent in the manufacture of the modules is shown in Table 1. It was concluded that a significant reduction in the engineering and technical hours can be achieved with better use of a shared BIM. Production hours are defined as labour hours spent directly on production (logistics, drilling, plasma cutting, band saw cutting, sawing and drilling in line, plate cutting, plate bending, welding tests, chamfering, assembly, welding, painting, bolt screwing, etc.). The fabrication effort was highly

dependent on module shape as shown in Table 2. For example, the fabrication effort for corner modules is 74% greater and for modules with internal part is 52% greater than for simple (planar) modules.

Table 1: Factory effort in person-hours

Fabrication	Person hours
Engineering technical support	10200
Production	41800

Table 2: Fabrication effort for different module shapes

Fabrication	Hours per tonne	% increase
Simple (planar) module	54.5	-
Module with inner parts	82.9	52%
Corner module	94.6	74%

A significant improvement in production efficiency was evident with experience as progress was made through the building levels. Comparing the hours/tonne required for assembly and welding of similar shaped modules in levels 2 and 5 provides a good indication as shown in Table 3.

Table 3: Comparison of assembly and welding hours for levels 2 and 5

Fabrication	Level 2 (hours/t)	Level 5 (hours/t)
Simple (planar) module	44.8	42.0
Module with inner parts	84.1	44.7
Corner module	112.5	83.0

As there is a very significant amount of repetitive work in the fabrication, further efficiency gains can be realized by rationalizing materials to minimize variability. This includes plate grades and sizes, shear stud sizes, bolt sizes, etc. During the project, there was deliberate variation to study a range of alternatives.

Two welding processes were used in the manufacturing of the modules: (a) 135 / GMAW: metal active gas welding (MAG welding) for butt welds and fillet welds and (b) 783: Stud welding with ceramic ferrule protection. Automation of the welding processes for both stud and butt welds should lead to significant productivity gains.

## QUANTITIES OF CONSTRUCTION MATERIALS

The quantities of materials used in the construction of the pilot building in SC are compared with those used in the RC DUS building in Table 4. In the RC DUS, the formwork is measured in m<sup>2</sup>. In the case of the SC pilot, only the small gap between wall modules joined by dowel bars (level 1 to 4 – see Figure 5) needed to be closed for concreting. The figure for formwork in kg is the weight of metallic strips used to close this gap (no formwork was required for the top two levels which were welded).

Concrete quantities are very similar as wall and floor thicknesses were kept the same for both buildings. The RC DUS requires reinforcement in both the walls and floors. In the SC pilot, no reinforcement is required in the walls and a reduced quantity of reinforcement is used in the floors as the bottom steel plate provides tension reinforcement.

The figure for module steel includes all steel that is part of the modules when they leave the factory. This includes the plates and all elements welded to them (studs, tie bars, couplers, T-stiffeners, support points for dowel bars) as well as vertical dowel bars, removable tie bars, etc. The figure for ancillary components covers all items delivered separately from the modules. Some of these were structural (like horizontal dowel bars and their supporting frames and the angles used for construction stage support of the floor modules); others were temporary erection aids removed after installation and may be reused.

The SC pilot requires no conventional embedded plates. However, where heavy loads are to be supported on walls or floors, it may be necessary to provide external strengthening (e.g. by welding a patch plate onto the module faceplate), but the problems associated with the installation of conventional embedded plates are completely eliminated. The RC DUS has circa 1000 embedded plates.

Table 4: Comparison of material quantities in the RC DUS and SC pilot building

	RC DUS	SC Pilot
Formwork	4223 m <sup>2</sup>	1510 kg
Concrete (m3)	1108	1045
Reinforcing steel (kg)	209000	12561
Modules – steel (kg)	-	419089
Ancillary components (kg)		43193
Embedded plates	1000	-

## CONCLUSION

SCHEDULE project was a major European collaborative effort to gain expertise in the modelling, detailed design, manufacture and construction of buildings using SC construction. It enabled the project team to evaluate the technical and economic implications of this technique as well as its impact on construction schedule. Many lessons were learnt in the course of the project and the key one are summarized below:

- Early involvement of all stakeholders is important for the success of a project using modular SC construction due to the impact that design, manufacture and construction have on one another.
- Building information modelling (BIM) greatly facilitates the development and refinement of the design, avoidance of clashes and communication of the design between project stakeholders. It should be implemented on a shared platform and based on an agreed modelling specification.
- Careful consideration should be given to how the building is divided into modules as this is impacted by manufacture, transportation and construction considerations. Larger modules and complex shapes might facilitate construction but tend to lead to higher manufacturing cost; the balance between the two should be evaluated early on in the design.
- Manufacture of modules entails a highly repetitive process and warrants investigating the potential for automation of several of the manufacturing steps.
- Elimination of reinforcement from most areas means there are far fewer hot spots to resolve on site.
- A range of methods for joining modules on site were investigated. All were technically possible but vary in ease of implementation, cost and functionality. For example, the dowel bar connection,

whilst easy to implement on site, leads to additional fabrication effort and is not suitable for structures requiring water-tightness. The construction aspects of the different joint types and a comparison of the SC construction schedule of the pilot building with the RC construction schedule of the DUS RC building are discussed in more detail by Etienne (2024).

## **ACKNOWLEDGMENT**

The project was undertaken by project partners The Steel Construction Institute, EDF, CEA, EGIS, Bouygues, Peikko, OCAS NV and ArcelorMittal Industeel. It received funding from the Research Fund for Coal and Steel under grant agreement No 800732 and industrial funding from ENRESA, Framatome, ORANO, ADF and the project partners.

## **REFERENCES**

- EN 1090-2:2018 Execution of steel and aluminium structures. Technical requirements for steel structures, 2018.
- Huguet, M. and Tuscher, J.L., “Design of a full-scale Steel-Concrete (SC) demonstration building (SCHEDULE project), Structural Mechanics in Reactor Technology, Tokyo, 2024.
- Etienne, D., “On-site construction of a steel-concrete (SC) demonstration building (SCHEDULE Project):”, Structural Mechanics in Reactor Technology, Tokyo, 2024.