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ON-SITE CONSTRUCTION OF A STEEL-CONCRETE DEMONSTRATION BUILDING – SCHEDULE PROJECT

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ABSTRACT

Steel Concrete composite (SC) (made of two steel plates with studs, connected by tie – bars and infilled with concrete) offer the advantage of decreasing the duration of construction on site. To demonstrate the feasibility and potential savings of SC structures, as well as to get lessons learnt on the overall industrial chain (including BIM modelling, design, modules fabrication), a major European project was undertaken, with the construction at full scale of a replica of the EDF diesel generator building (DUS). This paper is focusing on the construction on site of the building, detailing the main phases and activities. The description of the overall project and of the design are covered in other papers.

During the design phase, the methodology for the construction on site was studied, leading to the definition of ancillary components for enabling the installation and connection of the walls and slabs modules. At the top of the building, two corners included an APC shell wall and a nuclear spent fuel pool, to assess their constructability with SC structures. The pool modules included leak detection channels along the joints welded on site. Three methods for wall modules connection (embedded dowel bars, prestressed bolts and welds) were used and assessed. The floors were connected to walls using bolts with on-site drilling and rebars screwed in couplers pre-welded to the wall faceplates.

A comparison of the manpower, schedule and material between reinforced concrete and SC was established, concluding on the SC structures benefits. Some potential improvements related to on-site construction methods (including welding) were also highlighted.

INTRODUCTION

The main interest of modular Steel Concrete (SC) components is to reduce the works activities on site, limited to the installation and connection of the prefabricated steel modules and to concrete pouring. The European project SCHEDULE consisted in the construction at full scale of a replica of the EDF diesel generator building (DUS), using these modular SC structures. As EDF has built 58 such buildings in classic reinforced concrete, a comparison of manpower, schedule and materials was possible.

The building (24.10 m long x 12 m wide x 14.90 m height) is made of 6 levels of walls and 4 slabs (including the roof). The levels 5 and 6 are specific as they include an APC shell and a nuclear spent fuel pool, and as the wall modules connection is done by welds. The connection of the wall modules is done with embedded M30 dowel bars (EDF patent) for the levels 1 to 4.

The design of the building has been carried out by Egis. The modules have been manufactured and delivered to the site by Peikko. The construction on site has been realized by BCEN (Bouygues Construction Expertise Nuclear, a subsidiary of Bouygues Travaux Publics), on the EDF site “Les Renardières”, around 60 km south of Paris. A Tekla 3D model has been developed by EDF and used all along the project for the design, modules manufacturing and construction on site. During the design phase, the methodology for the construction on site has been studied by Bouygues Travaux Publics, resulting in the definition of ancillary elements necessary for the installation of the modules and the layout of short welded threaded studs used for the temporary fixation of these ancillary elements. The description of the overall project and of the design of the demonstration building are described in separate papers (Burgan and al. (2024), Tuscher and Huguet (2024)).

SITE AND STAFF ORGANIZATION

The layout and organization of the site is shown on figure 1. For such kind of construction, the main point is to have enough dedicated areas for the storage of the modules before their installation. The south zone, marked in green, was dedicated to the storage of slab modules and miscellaneous components. The wall modules were requiring the bigger storage areas, which are shown in blue, with 3 specific zones. The orange zone, north of the building and close to the tower crane, was mainly for the storage of the M30 embedded dowel bars frames (levels 1 to 4 construction) and of the slab rebars. During the second part of the construction (levels 5 and 6), the pool modules were also stored and partially assembled in this zone.

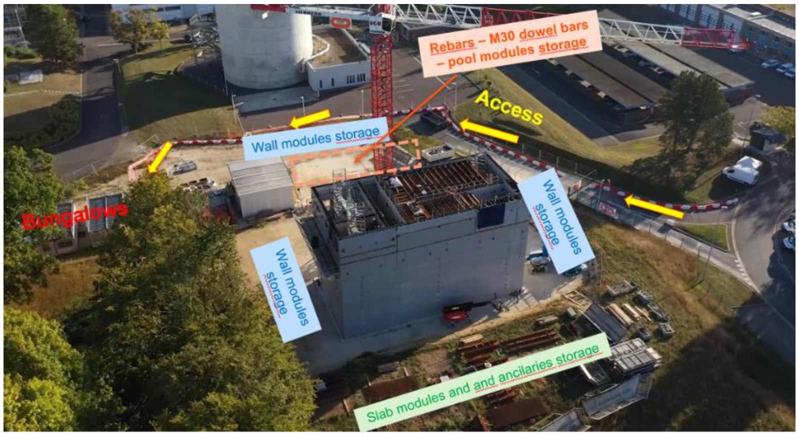

Figure 1. Organization of the site - building at roof level

All the modules handling operations were performed by the tower crane (LIEBHERR crane 250 EC-B 12 Litronic), with a capacity to lift 6.7 tons at the maximum span (40 m). Access of the workers for modules installation and concreting was from nacelle, cast slabs or P3D working platforms. These last ones were attached to the wall modules once the walls were concreted.

The construction team of BCEN was composed of the management staff (1 works engineer + 1 trainee engineer + 1 site construction manager) and of the workers (1 team leader, 1 tower crane operator and an average of 7 workers). One interest of these SC structures is to require a relatively small construction team on site, by comparison with a traditional reinforced concrete construction. EDF was in charge of the supervision of the construction activities, including monitoring compliance with health, safety and environment requirements as well as managing risk generally on site.

TYPICAL CONSTRUCTION SEQUENCE

The building is constructed level per level. For a typical level with a slab, the wall modules are installed, then the slab modules are placed and connected to the wall faceplates. The walls can then be concreted. The slab concreting is done three days minimum after the wall concreting so that the walls can withstand the slab fresh concrete weight.

FOUNDATION RAFT CONSTRUCTION

The raft is a standard reinforced concrete (C25/30) base slab, 25.10 m long, 13.00 m wide and 0.70 m thick. The specific point in relation with SC is the necessity to install the starter bars with accuracy in terms of both their position and verticality. This is necessary to avoid clash with level 1 wall modules faceplates, including studs and tie-bars. These starter bars have a L shape and diameters ranging from 16mm to 32mm. They are located midway between positions of studs and tie bars, with a spacing of 200 mm. For securing their location, a template tool was designed and manufactured by BCEN (figure 2). It was made of two plywood sheets with slots in both sheets. Verticality is ensured by the aligned holes in both sheets.

Figure 2. Template tool (left) - starter bars installation in the template tool (right)

DELIVERY AND STORAGE OF THE MODULES

The wall and slab modules were delivered to the site by Peikko trucks, according to the construction progress. The wall modules were stored vertically on the trucks. The module unloading was done with the tower crane. The slings were attached to pierced lifting plates located at the top of the module.

Figure 3. Wall modules stored on a truck (left) - wall module unloading (right)

The module was then moved with the tower crane to its storage position on the site, guided by two workers with ropes attached to it. The stored module was resting on timber battens and was stabilized with steel props fixed to concrete blocks. The fixation on the module was realized with temporary steel plates bolted to threaded studs pre-welded to the module faceplate in the factory (figure 4). The slab modules were also unloaded with the tower crane using lifting ears welded on the flange of the T stiffeners.

Figure 4. Wall modules storage with stabilizing props (left) - wall module transfer (right)

FIT OUT OF THE MODULES

Prior to installation, the modules were fitted with construction ancillary elements to enable the assembly on the building (figure 5) : levelling jacks at the bottom, installation guides and leveling jack supporting plate at the top. These components were bolted to the modules using pre-welded threaded studs. The vertical dowel bars (used for the connection between modules at horizontal joints up to level 4) were moved to their raised position as they were lowered inside the module during the truck transport.

Figure 5. Levelling jack (left) – vertical guides (middle) – dowel bars raising (right)

INSTALLATION OF LEVELS 1 TO 4 – CONNECTION WITH EMBEDDED DOWEL BARS

Each module was lifted by the tower crane from the storage zone up to its final place on the building. During the lowering, the module was pulled against the long vertical guides, ensuring the correct position and avoiding clash with the raft starter bars (case of level 1) or with the protruding vertical dowel bars of the module below (case of levels 2 to 4). To ease this lowering operation and fine tuning the longitudinal position, 2 workers were guiding the module with ropes, staying at a safe distance (figure 6).

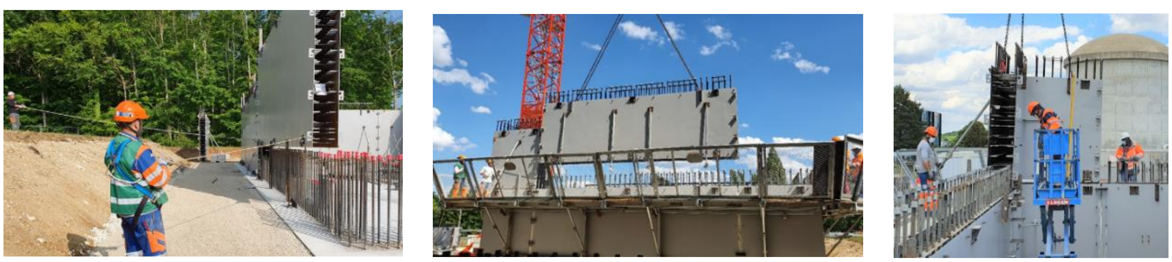

Figure 6. Wall module installation (level 1 on the left – level 2 on the middle and on the right)

The module was accurately levelled using the small jacks, to get a horizontal gap of 20mm with the lower level. The module was then fully released from the tower crane and supported only by the jacks. The stabilization steel props were attached to concrete slab or to working platforms, providing temporary support prior to wall concreting (figure 7). They were also used to adjust the verticality of the module.

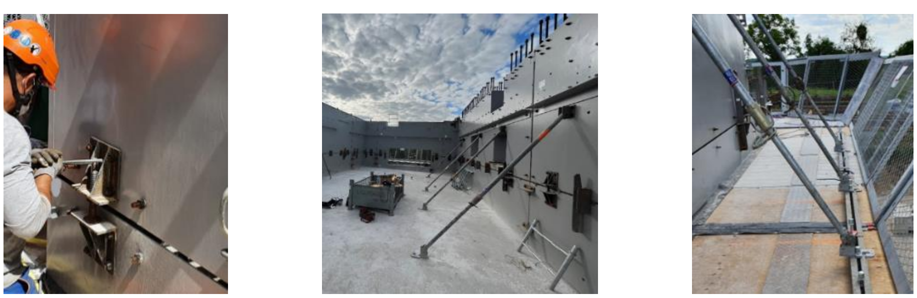

Figure 7. Adjustment with levelling jack (left) – stabilization steel props (middle and right).

After the installation of wall modules, the horizontal dowel bars M30 were placed along the vertical joints (2 racks per joint). They were delivered assembled into frames by Peikko. The frame was lifted and lowered inside the wall by the tower crane, with the help of a worker positioned in a nacelle. The rack was lowered in the middle of the wall to avoid studs, then shifted horizontally to its final position close to the faceplate and positioned/blocked in its supports (figure 8). Prior to horizontal dowel bars installation, the tie bars located along the vertical joint had to be removed. They were refitted once the dowel bars in position, by screwing them from the outside into couplers pre-welded inside the module (figure 8).

Figure 8. Horizontal dowel bars installation (left) - frame bracket (middle) - removable tie-bars (left)

The final step prior to concreting was to seal the vertical and horizontal gaps between modules. This was done using timber formwork attached on the outside of the module with steel angle ties and additional fixation means. This operation was time-consuming and required a carpentry workshop on site. The angle ties also enabled to align the faceplates along the joints in case of small misalignment between 2 adjacent modules. Due also to local concrete laitance leakage occurred with this timber formwork, an alternative method was developed during the construction, using a steel strip (with foam applied to its edges) fixed on the inside of the joint (figure 9). This has the benefit that the concrete pressure acts to seal the gap by pushing the steel strip against the faceplates. The installation of these strips was also much faster.

Figure 9. Joint sealing with timber formwork (left and middle) - with inner steel strip (right).

INSTALLATION OF WELDED WALL MODULES (LEVELS 5 AND 6)

The construction of the levels 5 and 6 faced several specificities and difficulties due to the APC shell part and to the nuclear pool (figure 10). For the standard modules, the installation was generally faster, as there was no works related to joints sealing and embedded dowel bars installation. However, the preparatory works for the welding of modules, and the welding operations themselves, were time consuming.

Figure 10. Pool and APC shell at level 5.

The modules had backing plates at the bottom (for ease the welding on site), in the inside of the modules (figure 11) and penetrating in the underneath module. This was consequently requiring a good geometry of the modules, but this was the case. The APC shell did not also bring any difficulty regarding the module installation (figure 11).

Figure 11. Level 5 module with backing plate (left) - APC shell module installation (right)

Standard modules joints were fillet welded (red fillet on figure 12) using the welding process MAG 138 (metal active gas welding), performed manually. The nominal gap between faceplates was 30 mm with ± 10 mm for installation tolerances (figure 12).

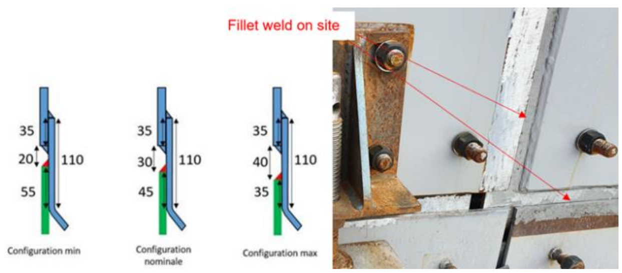

Figure 12. Fillet weld for standard modules connection

The APC and pool modules were butt welded (figure 13). A first pass was achieved at the root face with the TIG process 141 (Gaz Tungsten Arc Welding). The filling of the joints was done manually with the process 111 (shielded metal hand arc welding). The nominal gap (at root) was 7mm, to allow for manufacturing and installation tolerances. The real gaps on site ranged from 7 to 12 mm, but up to 20 mm for few joints, which resulted in a very long time for joint filling.

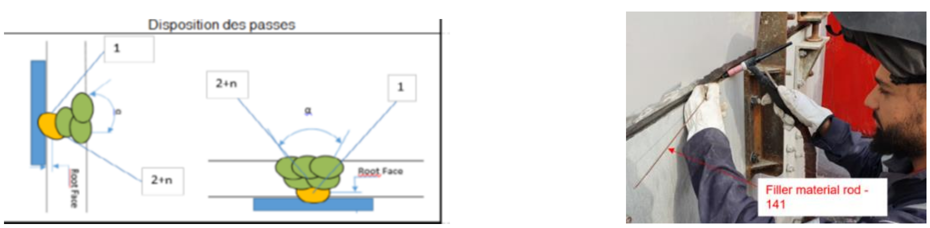

Figure 13. Butt weld for APC and pool modules connection (left) – TIG welding at the root (right)

NDT (non-destructive tests) were done according to EDF requirements : 100% visual inspection, PT (penetrant testing, 100% for buttwelds, 10% for fillet welds), ultrason (20% for buttwelds). The welding activities were sub-contracted to ADF (Atelier De Fos). The welding preparatory works took much time and some mitigation measures have been highlighted for future projects with welded connections. The access for the welders was from the level 4 slab or from nacelles, using tarps to ensure protection against wind (figure 14).

Figure 14. Fillet welding (left) - plate grinding (middle) – APC shell butt welding (right).

PRESTRESSED BOLTED CONNECTION.

A prestressed bolted connection system had been tested on four vertical joints at level 5, using “Hollo-BoltsTM (from LINDAPTER)” fixed in holes drilled on site through the plate of one module and the backing plate of the adjacent module. The implementation of this connection was very fast, easy, and required less works than the connection with embedded dowel bars.

Figure 15. Pre-stressed bolted connection – joint with straight backing plate before holes drilling (left)

WALL CONCRETING.

Each wall level was fully concreted in one time. The total volume of concrete was around 110 m3 for the 2.4 m high wall levels. The concrete was a standard C30/37. The consistence class was S4 to have enough fluidity and ensure that the concrete would well fill the module. The concrete was poured into the walls with a concrete pipe and vibrated from the top of the wall with pokers handled by workers (figure 16).

Figure 16. Wall concreting (left) - concrete top surface (middle) – vibration at large opening (right)

The walls were concreted up to 1 or 2cm below the module top level. At the location of large opening in the walls, small square holes were made in the horizontal plate to enable the vibration of the concrete and avoid trapped air just below the horizontal closing plate of the opening (figure 16).

SLAB CONSTRUCTION.

The first step was to attach to the wall faceplates the slab support L angles (figure 17), using pre-welded threaded studs. Long slotted holes in the L angles allowed for vertical levelling. Short filet welds were then done, so that the L angles were able to support the weight of the steel floor and construction loads.

The slab modules were then lifted with the tower crane. These modules were designed to be 100 mm shorter than the gap between the supporting walls, providing a 50 mm clearance on either side. They were lowered in a dedicated zone where all construction ancillaries were removed. The remaining 40 mm long pre-welded threaded studs along the wall faceplates made the lowering of the module a little tricky.

Figure 17. Support L angle installation (left) - floor module installation (middle and right)

The next step was to bolt the slab T-stiffeners webs to the wall face plate with double angle cleats. These were first bolted to the wall faceplate into nuts pre-welded (tack welds) by Peikko on the inside of the module faceplate (figure 18 – left). Then, the T-stiffener web and the two angle cleats were drilled in one operation and bolted together with M20 bolts (figure 18 – middle). This drilling operation has worked very well and was a relatively fast work. The longitudinal joint between floor modules was sealed from above with a steel strip clamped down to the module plates using a U-shaped section (figure 18 - right).

Figure 18. Slab T-stiffener connection to wall (left and middle) - Longitudinal joint sealing (right)

The slab had only top reinforcement layers (HA20), anchored in the walls thanks to couplers pre-welded from the inside of the wall and with a short protuding part to enable the rebar screwing. In the wall, headed bars were already fixed in the couplers (in the fabrication shop) to provide anchorage (figure 19).

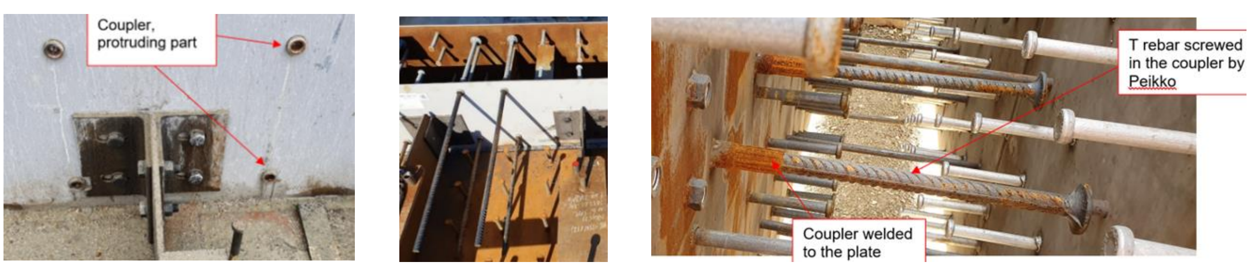

Figure 19. Slab rebars anchorage in the wall modules

POOL

The pool was split in 3 levels (slab, levels 5 and 6), each being made of 2 U shape modules stored and assembled by butt welds on the ground, then lifted by the tower crane and installed as a single large module (figure 22). To ease the welding of the slab, the 2 modules were assembled in vertical position (figure 20).

Figure 20. Pool floor modules assembly and butt welding on the ground

Leak detection channels (figure 21) were present at some stainless-steel plate's joints welded on site. Silicon joints were put on both part of the channel as a glued U-shape strip on the male part of the joint (red) and a straight strip on the female part (green). Their function was to ensure the tightness of the channel against fresh concrete (during pool concreting). This leak detection channel was successfully tested at the end of the construction, but it should need to be improved for industrialization.

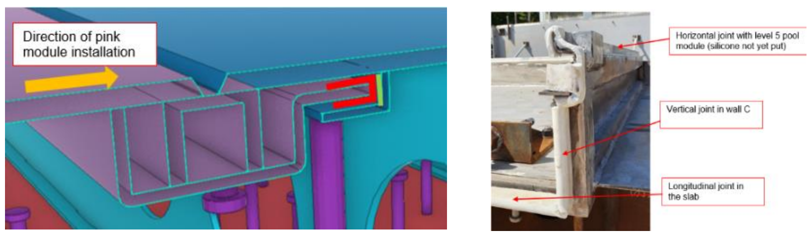

Figure 21. Leak detection channels with sealing joint

Figure 22. Pool modules installation (left and middle) – horizontal joint butt welding (right)

Horizontal joints between the installed pool modules were then butt welded (figure 22 – right). The pool (floor and walls) was poured with a self-compacted concrete. To ensure that the concrete would fill the whole floor module and avoid any trapped air, the concrete was poured from one wall, then guided by the longitudinal stiffeners of the floor module and pushed towards the opposite wall.

AS BUILT SCHEDULE AND COMPARISON WITH REINFORCED CONCRETE.

Table 1 is providing the comparison of construction schedule, workforce and worked hours between the SC demonstration building and a representative standard reinforced concrete (RC) DUS. The comparison starts after the raft completion, e.g., only for the superstructures (walls and floors). The split between levels 1 to 4 and levels 5 – 6 is to account for the additional complexity with the APC shell and pool. A saving of 1.7 months (31%) was obtained for levels 1 to 4, with embedded dowel bars connection. It is a little less (1.6 months, 22%) when looking at the total building including the welded connections for levels 5 and 6, due to the time for the APC shell and pool and to the welding preparatory works. The SC pilot building required much less persons on site during construction compared to RC DUS.

Table 1 Comparison of time and personnel in the construction of the RC DUC and SC pilot building

	RC DUS	SC Pilot	Difference (%)
Months for levels 1 to 4	5.4	3.7	-31%
Months for levels 1 to 6	7.2	5.6	-22%
Workforce (persons)	30	8 (+ 5 for 1 month during welding)	-73%
Effort (hours)	23 500	7 300	-69%

CONCLUSION

The SCHDULE project has successfully demonstrated the feasibility to design and build a SC nuclear building. Expertise, feedback, and ways of improvement have been gained for the on-site construction part. The foreseen savings on the schedule and worked hours have been confirmed. Considering SCHEDULE was a first of a kind, and based on the numerous lessons learnt, it can be anticipated higher savings for future SC project and be concluded on the high interest of SC structures in nuclear field, but not only.

One key design and construction aspect is the wall modules joining. Two methods were used. The first one with embedded dowel bars was efficient, provided tolerance for the module geometry and installation, but required several successive tasks. The second with fillet weld connections took more time but mainly due to the preparation of the joint surface. Butt welds, limited to the APC shell and pool, were also time consuming due to bigger gaps than anticipated. Mechanized welding should be considered for future project with welds joining. A third connection method was locally tested, with prestressed bolts, and proved to be easy and fast. Considering potential improvements for welded connections, the 3 solutions are efficient and can be used. For the connection of slabs to walls, the bolted solution used for SCHEDULE was fully satisfactory. Some improvements were suggested for ease the construction on site, reduce the schedule and enhance the construction quality and safety.

Figure 23. Building completed.

ACKNOWLEDGMENT

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