The proposed research center that is known as SU-NAC which is an acronym for “Sabancı University Nanotechnology Research and Application Center” consists of an 11 meter high two-story building with footprint dimensions of 40 meter length and 60 meter width, which is partially surrounded by an atrium space that is enclosed by a structural façade designed to represent the lattice structure of a nanotube as shown in figure 1. The 134 meter long structural façade consists of 73 meter high and 50 cm thick prefabricated structural elements of high strength C60 grade white concrete that are aligned along a hypothetical oval plan surrounding the two-story high building. The façade that is constructed of 53 prefabricated units of three different types encloses an unobstructed atrium space around the two-story building with a footprint area of approximately 1,185 m². The atrium space is capped by a heat insulated concrete roof with an area of 1,800 m² and weighing 560 kg/m² that is supported on steel beams spanning the variable opening space between the two-story building at a maximum distance of 15 meters and cantilevering over the structural façade at a maximum of 7 meters. Figure 2 provides an internal perspective view of the atrium. The structure, which is located in the Marmara Region of Western Anatolia part of the Turkish Republic experiences ground acceleration values in excess of 0.4g.

**Functional characteristics**

SU – NAC is constructed with different construction materials and construction techniques. The two-story building part of the SU – NAC is a cast-in-place C30 grade reinforced concrete structure. The atrium part is composed of prefabricated and insulated C60 grade reinforced concrete façade elements that is composed of CEM 52,5 white cement. The roof plate is composed of C30 grade reinforced concrete overlaying galvanized ribbed steel decking that span between S7-52 steel roof beams. The radial steel beams rest on steel belt beams that are continuously supported along the top of the façade elements. The connections between the radial beams and the steel belt beams and the connections between the steel belt beams and the prefabricated concrete structural façade elements allow rotations between the connected elements.

Aside its structural character as a support element for the roof, the prefabricated façade; measuring at approximately 1,000 m², is also the architectural centerpiece of the structure. The structural façade had to be transparent enough to allow the infusion of daylight and had to have sufficient strength and ductility to support the lateral and vertical loads due to the heavy roof load. Therefore, the two conflicting requirements of the façade had to be resolved within its solid structural part that formed 30% of the total façade area. The large façade surface required the prefabricated elements to be insulated as well. Therefore the façade had to provide the architectural and structural necessities of the atrium as well as the insulation requirements.

**Structural characteristics**

The structural façade of SU-NAC shown consist of three types of prefabricated elements that amount to fifty-three elements in total. Following their production and shipment, the prefabricated structural elements are installed within sockets that are prepared within a continuous strip foundation along the total length of the façade. The three-types of prefabricated elements shown in figure 3a-c, weighed 3.5 Tons to 7 Tons each. The roof loads that are collected by the radial beams are transferred to the belt beam that is aligned along the top of the...
façade. The belt beams are supported by the façade elements at discrete locations on top of steel plates that are welded to embedded steel plates within the façade elements. The prefabricated structural façade elements were designed for service level gravity load values of minimum 12.5 Tons and maximum 50 Tons. The precast elements were designed to withstand the imposed design loads individually. However, they were also connected to each other through the belt beam at the top and through rotation permitting rods through the contacting elbows of neighboring elements as shown in figure 4a-b. The use of the belt beam and the rods permitted the individual precast elements to be chained together for alignment purposes which limited the possibility of relative movement between the precast units during the construction phase and structural purposes that limited the degrees of freedom for vibrations that can occur throughout the façade. The steel roof beams that are composite with the reinforced concrete roof slab, rested on the prefabricated structural façade elements such that the connection allowed the rotations of the beams thereby preventing the formation of the fixity moments at the top of the cantilevered façade elements. The expected lateral movement of the roof plate that was connected to the main building was estimated and the façade panels were designed to withstand the expected bending moments that would be imposed on them as a result of the
lateral movement of roof slab. The belt beam was bolted to plates that were welded to plate anchored into the prefabricated structural units during production.

Each layer of the façade was designed such that the concrete was not stressed beyond 50% of the compressive strength at the service load level. In order to provide the required strength with the necessary ductility, doubly reinforced solution was used. Due to the presence of shear with respect to shear and torsion along with the bending stresses, proper continuous confinement of the concrete was extremely critical.

The reinforcements along the façade were continuous such that each reinforcement with a total length of 920 cm was bent at 10 locations along its span in order to follow the architecture of the prefabricated structural façade elements. The longitudinal structural continuity thus achieved was coupled at the nodes by confinement reinforcement along the full widths of the nodes that completely tied the vertical reinforcements. Figure 5 shows the typical cross section of the maximum reinforcement of the prefabricated structural façade elements.

The design of the prefabricated structural elements not only included the service loads and ultimate load but also structural design for loads generated during installation and construction phases when the prefabricated elements experienced a variety of maneuvers with changing support conditions at the early ages of concrete strength.

Prefabrication and installation

The initial realization and the completion of the project took place in 18 months between March 2009 and August 2010 that included many design and production phases. The structural design of the prefabricated structural elements lasted four months during which many revisions were made and many design ideas were considered. Following the conclusion of the structural design, detailed design drawings were generated during which the methodologies to produce the specific reinforcement cage were determined. The formwork producer was also incorporated into the project during the generation of the design and construction drawings of the prefabricated structural façade elements. The composite fiber reinforced plastic formworks were chosen for their ductility and ease of repair for the repeated productions that took place in three months. The limited structural cross-section of the façade elements with the requirement for doubly reinforced section required the design of a special concrete mix that provided the sufficient strength and stiffness and the required workability around the continuous reinforcement cage. Therefore, a special C60 grade concrete mix that included white cement and white
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mosaic aggregates with a maximum size of 10 mm and a slump of 15 cm was designed that allowed the placement of the concrete with a level of vibration that did not cause any loss of homogeneous aggregate distribution.

Production of the continuous reinforcement cage without any overlaps was an important challenge that had to be overcome for placement into a slender formwork with limited tolerances. After a couple of trials, the construction of a complete and a continuous reinforcement cage was succeeded as shown in figure 6.

Once the learning curve reached an optimum level, a crew of 6 workers bent and tied the cage for one prefabricated structural façade element in one work day. The rebar content of 1 m$^3$ concrete of the doubly reinforced sections varied between 300 kg and 350 kg. The fabrication of the rebar cage in its totality allowed ease of maneuver and placement into the composite formwork. Figure 7 shows the placement of a type – 1 rebar cage.

The composite formwork was constructed of a series of smaller formworks that were bolted together at the nodal locations of the finished product. The multi and sloped faced façade element had many points of contact and friction with the formwork that had to be released without forcing and deforming the formwork beyond a limit of deformation. The multi-piece design of the formwork allowed ease of formwork production, formwork cleaning and the ability to produce the three types of façade elements with a single repeating formwork unit thereby lowering the formwork costs.

The setup of the formwork which included the cleaning, bolting and fine tuning by the installation of the specially produced sloped shims to give the cast product the required side slopes also required the combined effort of 4 workers for one workday.

Prior to the production of the façade elements, XPS insulation layers were precision cut to match the space between the two layers of concrete that was to be cast. Each façade element had two reinforcement cages. Following the placement of one cage into the formwork, the top plates to be connected to the belt beam was embedded and then the concrete was poured and the insulation layers placed. A typical prefabrication sequence of the initial layer of the prefabricated structural façade element is shown in figure 8a-b.

Following the placement of the insulation layer, the second layer of the formwork was placed and shear studs were penetrated through the insulation layer that eventually created thermal bridging but providing composite action between the two layers of the prefabricated structural façade element. The design of the formwork geometry and formwork material was such that 85%
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of the surface area of the cast product was covered by the formwork which also provided thermal insulation, thereby trapping the moisture and lowering the dissipation of the heat of hydration that provided a self-curing mechanism.

Without the use of any special curing schemes, the products were de-cast after 12 hours at a strength grade of C30, which was sufficient for the products to be lifted and stored for shipment. Each prefabricated unit had 4 specially designed anchor locations that were placed with respect to the center of gravity of the façade element. The products were most of the time very easily de-cast by an overhead crane mobile crane that immediately transferred the products to the storage area. The typical de-casting and storage sequences are shown in figure 9a-b.

Prefabricated structural façade elements were later shipped to the site 20 km away from the factory in groups of three units where they were unloaded as shown in figure 10 and placed into pre-prepared socketed strip foundations. The erection of the prefabricated structural façade elements had an in-plane erection tolerance of 5 mm and an out of plane erection tolerance of 0.002 rad.

The prefabricated structural façade elements were lifted and placed into the sockets which were later non-shrink grouted. During this phase of construction, the façade elements were cantilevered. During the phase where the top roof support was not present, the façade had to be supported by its foundation in the event of an earthquake. Therefore the elements were designed as cantilevers for an earthquake that could occur during the construction. Late in November 2010 an earthquake of moment magnitude 4 did occur in the region during which the installed façade elements showed no sign of distress. Figure 11a-b shows the installation of the façade elements into the sockets that are later to be grouted. Following their installation, the prefabricated structural façade elements were bolted along their points of contact that allowed for rotation but prevented relative lateral translation between the neighboring elements. The bolting sequence that took place at the elbows is shown in figure 12.

Following the completion of the façade, the steel beams were spanned between the two-story building and the façade over the atrium space. The beams were fixed connected to the building and simply supported on the façade. Following the placement of the beams, corrugated steel decks were spanned between the beams through which the shear studs penetrated into the roof slab. Following the placement of the steel lattice and concrete, insulation and a sloped topping was placed. The installation of the façade elements took approximately 3 months and the construction of the roof slab lasted about 4 months.

Conclusion

The prefabricated design and construction of the structural façade was an important challenge where a solution to satisfy the architectural, functional and structural requirements of the façade within a single step of construction was achieved. Figures 13 and 14 show the exterior perspective of the completed structure. Initial architectural design called for separate vertical support elements for the roof; however the design by YMP incorporated into the façade all the structural requirements that were needed to provide for the large atrium space of SU – NAC.