14 The Forum Shopping Center Project

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Introduction:

Alkali resistant glass fibre reinforced concrete is a ductile cementious material that can be used to design and build structural concrete elements that are thinner than the concrete cover of a typical reinforced concrete element. Thickness values in the vicinity of 10mm; previously unheard of in reinforced structural concrete design, is a typical outcome of GFRC design. Presented in this paper is the design and construction of a geometrically complex façade for the FORUM Shopping Mall.

Keywords:

GFRC, plates, shells, façade

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Reinforcing concrete with glass fibres:

Due to its fibrous nature, GFRC elements can handle stresses up to a certain level in a ductile manner without the need to rely on the tensile strength of an embedded steel reinforcement. The lack of steel reinforcement makes the concept of concrete cover irrelevant for a GFRC element thereby reducing its selfweight. Certain elements within a structure such as the façade elements are frequently designed to resist wind, seismic and selfweight loads and designed to respond to movements caused by temperature gradients and the movements of the parent structure. Numerous academic and engineering project studies have presented the fact that GFRC can be used to design and construct plate elements with a minimum planar width to thickness ratio as large as 100 without the need to rely on an embedded reinforcement other than the fibres.

A design project:

Yapı Merkezi Prefabrication Inc. has completed an engineering project for the design and construction of a 5.000 m^2 façade of a shopping mall. Roughly 20 meters high, the curved and tilted façade is about 250 meters long. The facade was defined within a three – dimensional space and had unsymetric and singular curvatures and tilts along its surface that necessitated the design and configuration of 1.815 prefabricated elements with dimensions varying between 100 cm and 200 cm. The installation that started in June 2010 took approximately 6 months.

The surface was studied in detail within a three dimensional render and divided into discrete façade units that followed the curvatures and alignment of façade within a smooth transition. Image – 1 shows a part perspective of the project and illustration – 1 shows a part elevation drawing of the project.

Image- 1

Illustration – 1

Prefabrication and installation:

The façade elements were produced by spraying a premixed GFRC on composite molds. Specially designed steel connection elements were embedded and properly developed into the façade elements. The façade elements were bolted to the steel lattice composed of rectangular steel elements that provided the structural link between the concrete façade elements and the parent structure.

The façade elements that had parallelogram shapes were supported at 4 points, two of which provided the support for the vertical self weight load and the remaining two the stability supports against the perpendicular lateral loads. The connections between the GFRC façade element and the steel lattice were provided by embedded plate elements that were hooked and bolted to the rectangular steel lattice elements. Illustration – 2 shows a part drawing of a typical connection element between the façade and the steel lattice.

The façade elements were designed with respect to bending, taking into consideration the double axis bending influences due to the positioning of the supports. The supports that were typically aligned in a rectangular fashion provided a two-way plate behavior to the façade elements that allowed for a reduction in the façade plate thickness down to 20 mm.

Image – 2 and 3 shows typical façade elements that are connected to the steel lattice in the background. Image – 4 shows a part of the tilted steel lattice that provides the frame for the curved façade. Image – 5 shows the installation of the façade element to the steel frame.

Image 2

Image 3

Image 4

Image 5

Design loads:

Following the analytical design, the façade elements were tested with respect to static design loads and impact loads. It is a well known fact that the slender nature of the GFRC elements creates a vulnerability to the effect of hard and soft impacts. For the hard impact test, a 1 kg steel sphere were dropped at a target along the façade element a number of times from a height of 170 cm in order to determine the fracture and energy absorbing capabilities of the designed elements. The test was meant to mimic the impact of hail and random projectiles that could hit the façade due to vandalism. The soft impact test was conducted to observe the façade behavior when heavier weights with a large surface area and less stiffness than a hard object hits the surface. To this end, a 50 kg sand bag was released on to the façade through a pendulum to simulate the impact of a 100 kg man on the façade at 10km/hour speed. Since the level of the façade was flush with the concourse level, the occurrence of such an event was deemed probable. Image – 6 shows the static test conducted on the product sample. Images – 7 and 8 and illustration – 3 shows the tests conducted on the full scale product with respect to static loading, hard impact loading and soft impact loading. In the static test, the load units had gaps in between in order to prevent the formation of arching between the blocks.

Corrosion:

Aside from design under immediate mechanical effects, the façade elements were also designed for time dependent corrosive effects due to climate and air pollution. The humid weather of the city of Istanbul, frequently experiences temperatures between 0ºC and 35ºC with varying degrees of carbon monoxide depending on the seasons and the time of the day. The corrosive effects of the accumulating smog on the façade with humidity and temperature could create ph levels in the vicinity of 5. To this end, GFRC samples with the same thickness as the intended façade elements were exposed to ph levels of 2 and 13 in order to observe the corrosive effects of highly acidic and basic environments on the GFRC plate samples. The bending strength results of the dry control sample was compared with respect to the bending strength of immersed results and a cross sectional reduction of 15% was observed after constant immersion of the samples into hydrochloric acid and sodium hydroxide for 21 days. Images – 10 and 11 show the samples during immersion into corrosive agents and after immersion into corrosive agents. Illustration -- 4 shows the effects of corrosive agents on the flexural strength of the GFRC material after 21 days of exposure to acidic and basic environments with ph levels as low as 2,3 and 14.

Thermal effects:

The façade was external to the thermal layer of the structure such that it was completely exposed to the external weather. In other words, no thermal gradient was present that required the consideration of any temperature differential. However, the elongation and contraction of the steel lattice with the temperature and consequent effects on the concrete façade elements were considered such that the necessary.

Conclusion:

GFRC is a suitable material to design and produce concrete shell and plate elements without the need of steel reinforcement. Glass fibres can be used to improve the tensile strength and ductility of concrete and can be reliably used for design. The benefits of GFRC in terms of reduced self weights in façade design is a notable benefit for the design and construction of the overall structure.

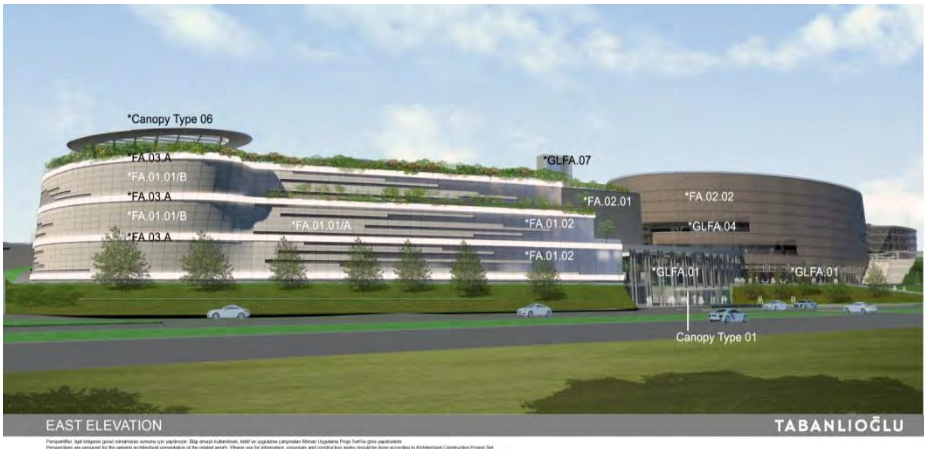

Image – 1

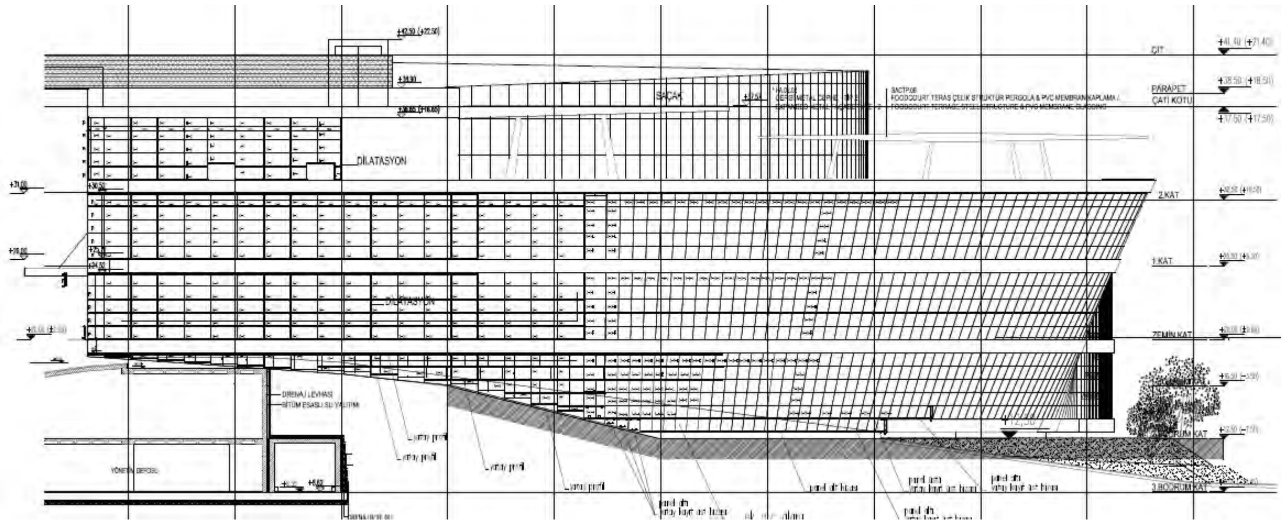

Illustration – 1

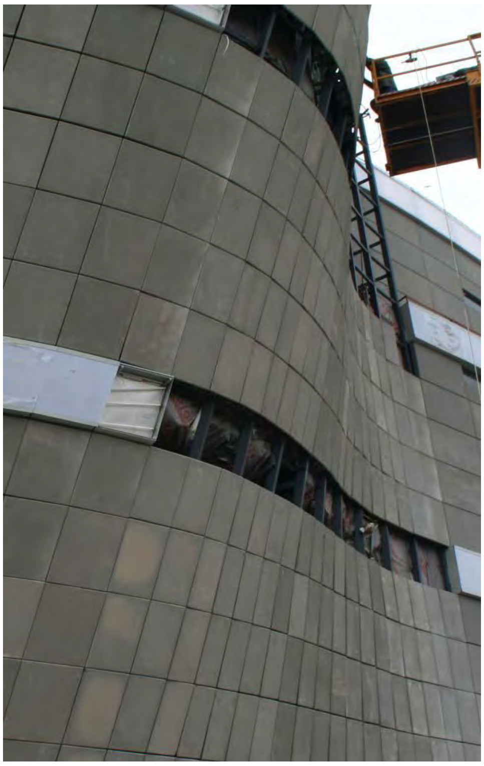

Image – 2

Image – 3

Image – 4

Image – 5

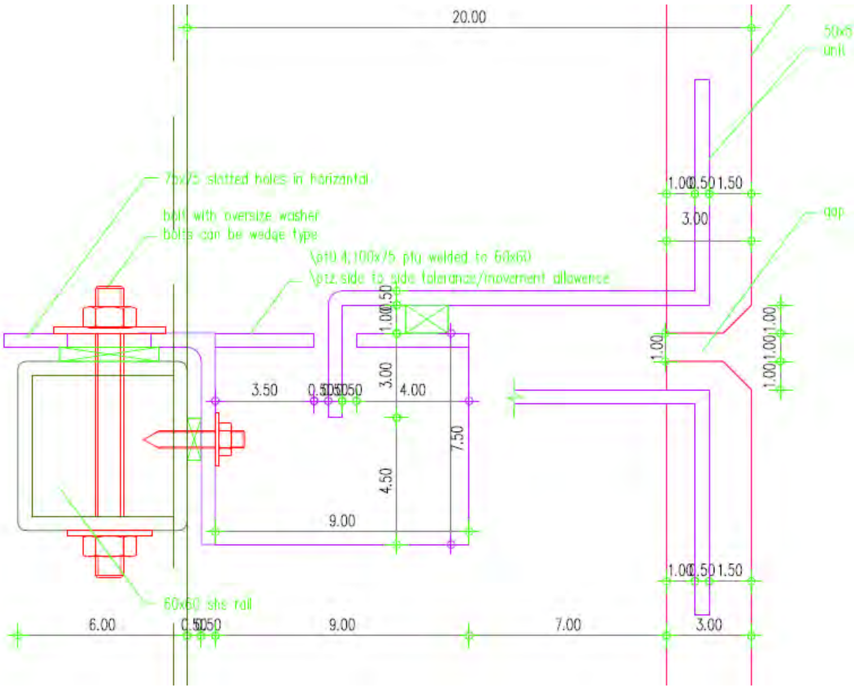

Illustration – 2

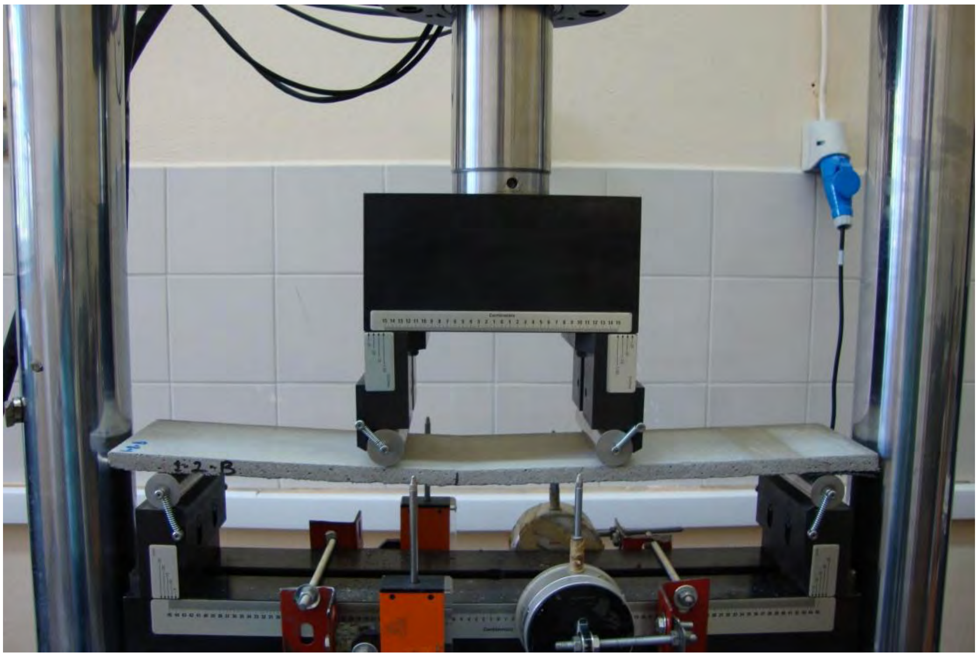

Image – 6

Image – 7

Image – 8

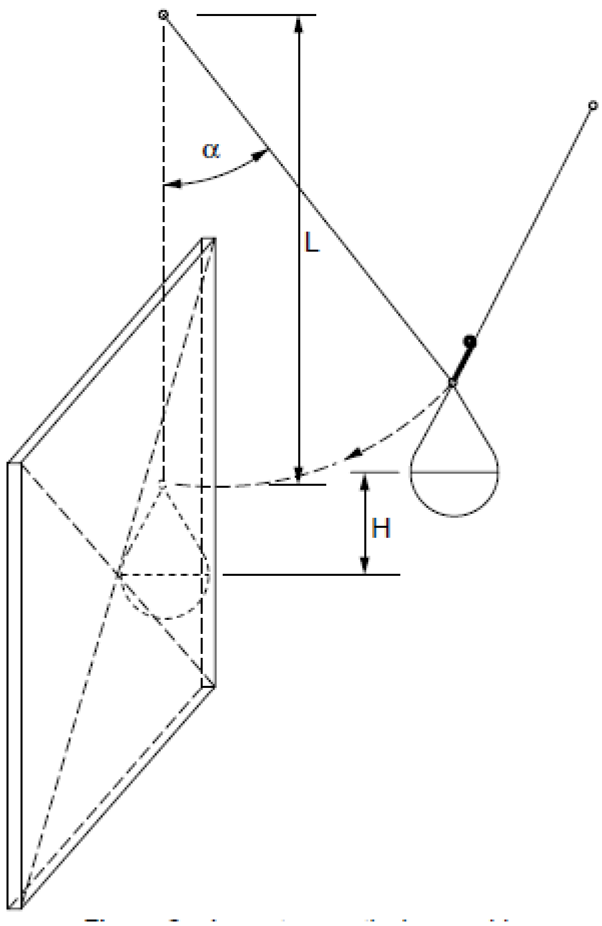

Image – 3

Image – 10

Image – 11

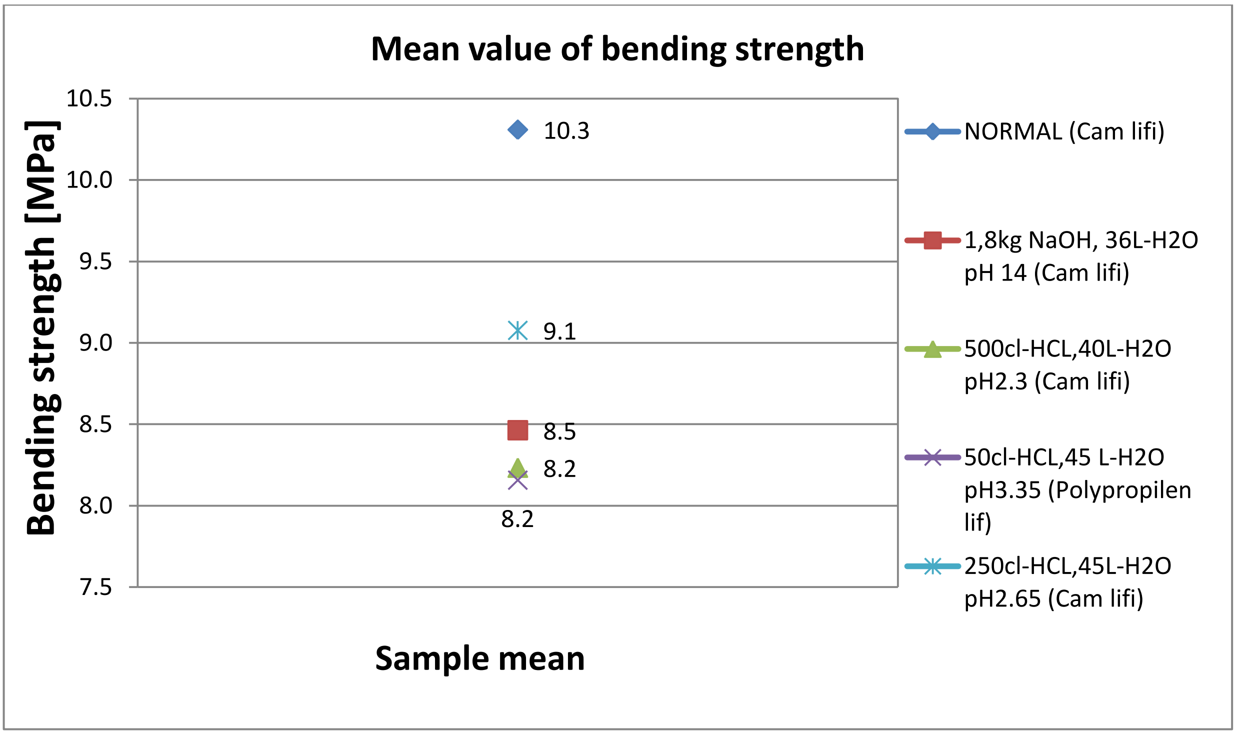

Illustration - 3