30 Anchoring Into Limited GFRC Thickness and a Solution for Lightweight GFRC Facade Framing

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Introduction:

GFRC provides the possibility of covering large surfaces with material thickness and tolerance values on the scale of millimeters. The efficiency of the GFRC in terms of covering a large surface with low amount of material requires new perspectives on prefabrication, anchorage, storage and installation of plate and shell elements prefabricated by GFRC. This paper suggests a method for anchoring into concrete with thickness values between 5 to 10 mm, without the need to provide embedment cover typically required in ordinary anchorage systems and presents a patented method under the trademark: Pençe®. The paper also provides full façade solution with the connection and support details, which is also patented, under the trademark: Cephetül®.

Keywords:

GFRC, anchorage, tolerance, framing, shells

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Structural Facades:

A structure is composed of many elements that serve to support and provide reaction to a variety of loads imposed upon the structure. A structure is also composed of surfaces that serve certain structural and functional needs. For instance the slabs provide the major structural element within the load path where the imposed vertical loads are received to be transferred to the foundation as well as functioning as the diaphragm that distribute the seismic accelerations to the required elements through which they are transferred into the foundation.

The façade of a structure can serve both purposes. In the case of a shear wall, the façade not only provides the lateral load resistance system but also serves as the functional surface of the structure that provides a habitable space within the building. However, there are many structures where the façade of the structure is merely the skin surrounding the perimeter of the load resisting elements within. In other words, aside from the requirement of carrying its self imposed weights as well as loads imposed by winds and accelerations generated by earthquakes, a façade element can be considered to be functional elements that is expected mainly to satisfy certain functional and architectural needs.

Ideally, it would be beneficial if all the weight within a building were structural, however this is rarely the case and a certain part of the building weight is always non – structural that simply exists in order to serve a functional purpose. When an engineer comes across a structural design, he or she must either try to use as much of the weight as structurally as possible or try to reduce the weight of non – structural items as much as possible.

It is beneficial to design and construct the façade of a structure that is not part of the load bearing system with the least amount of material that is functionally possible in order to impose the least amount of force on the load carrying system. Ductility and stiffness of a façade system allows the system to respond to parent structural movements without developing resistance and maintain geometric integrity. GFRC is a cement based material that develops elastic modulus values in the vicinity of E = 20.000 MPa and compressive strains at failure up to 0,9% depending on the slenderness of the section and the amount of fibers used. With its inherent tensile properties and stiffness that can be used within an engineering degree of certainty, it becomes possible to design thin plate and shell elements of GFRC.

Anchoring Into Concrete

The connection of a concrete element to a structural element requires a load path between the two. This load path involves the setting up the interaction between the two structural elements through which the stresses can be transferred. When one thinks of a façade element that is hung vertically from the face of a structure the stresses that are imposed on the element where it is hung are shear stresses due to its selfweight. If lateral wind pressure against or away from the façade is applied than axial stresses either in compression or tension is also generated. Therefore, one can easily visualize the multi – state of stresses within the connection where the element is hung. When one thinks qualitatively, the stresses can be axial, direct shear and torsional or a combination of the three.

Steel is commonly used to provide connection for a concrete as well as reinforcing a concrete element. The interaction between the steel and the concrete is generally through bearing through surface indentations and the most common steel element that is used is the indented steel rebar where surface interaction takes place between the steel rebar and the concrete along the length of the rebar where it's embedded into concrete.

Recently, certain prefabricated elements use the wedged steel where the bearing within concrete is localized but spread into a large volume so that the compressive strengths are not exceeded.

However, both of the general two methods mentioned above require a large concrete volume which is not present within a GFRC plate. The façade element that can be designed within 10 mm frequently faces the problem of anchorage since the amount of material within the 10 mm is simply not present to anchor into. In other words, unless the plate is locally thickened a rebar cannot be embedded into it. Simple means of connections involves a steel rebar typically around 8 mm in diameters, bent into an L – shape where the short part of the L is embedded into the plate where it is locally thickened as shown in image –1. Although it is quite simple to show a plate produced with a minor increase in thickness within a limited region on paper, typically during production, this embedment thickness is frequently left to the discretion of the worker that results in uncontrolled amount of material use that eventually increases the thickness of the plate and its weight from its design value. Such an undue increase in weight may cause excessive façade deflections that may cause unsightly violation of architectural placement tolerances.

Image – 1

Therefore, the idea of a thin façade element that is sufficient with respect to plate bending behavior has to be made thicker in order for it to be attached to a parent structure, which makes a rather odd conclusion considering the fact that the idea of the GFRC is to achieve much with less material. In order to overcome this result, another connection schematic has been thought of where the material that was anchored into was structurally used along the surface rather than into its depth as shown in image – 2 which shows the horizontal cross section of a thin façade element shown to be connected to a frame in the back, through a protrusion from the façade element.

Image – 2

Image – 3 on the other hand shows a vertical cross – section of the façade element where the thin plate is anchored into the frame behind, again through a connection element protruding from the façade plate.

Image 3

Every material has levels of strength with respect to the type of stresses that can be resisted and concrete is no different. The compressive strength of concrete; being the highest, is followed by its direct shear strength which is followed by its bending shear strength. The lowest strength level of concrete is provided by its direct tensile strength which slightly overtopped by its bending tensile strength. So the question of how to achieve sufficient anchorage within a concrete layer that is 10 mm in thickness depends on what strength mechanism one is trying to provoke in concrete. It is obvious that an anchorage scheme that would rely only on the direct tensile strength of the GFRC would provide very limited support to the element. Such being the case, an anchorage design was attempted that relied on the direct shear strength of concrete.

Concurrent with this design concept, the shape of the anchorage that would provoke direct shear resistance within the material had to be determined with the maximum amount of interaction surface area provided by a minimum amount of anchorage material. To this end, a wedge shaped steel section was conceptualized that would provide anchorage within the thin concrete member. Initially, a rectangular plate was manufactured with sloped sides and internal circular holes with varying radii. The holes not only provide escape holes for air that could become trapped during placement but also excess anchorage support due to direct shear with the concrete seeping in the holes that wedges the Pençe® after setting. Due to ease of manufacture and efficient use of material, a circular shape was later elected as shown in image – 4. When such a shape was embedded into concrete, it was securely wedged in after the setting of concrete.

Image 4

The mechanics of the anchorage can be attempted to be defined quantitatively through the use of image – 5. If the anchorage initially has almost vertical sides with the horizontal with an infinitesimal angle, than the requirement for the balance of the forces in order to resist the imposed pull P1 would be:

$$\sin\varphi = \mu_s.\cos\varphi,$$ where

μ_s is the static coefficient interface friction. However at such a small angle it would be very difficult to achieve this condition since the vertical component of the reaction is very small due to the verticality of the member sides and the anchorage would easily slip away under the action of the large lateral component. In the case of a vertical element, the only resistance present [t_1] would be the surface bond that exists between the GFRC and the side of the steel plate.

However, as the sides begin to slope, the vertical component of the reactive force at the interface begins to increase and with the interface friction, begins to equalize the horizontal slipping component of the pull P1. Now, if these two forces begin to equalize each other, the failure could occur by either the concrete crushing under the effect of the cosine component of the reaction force or slide along a failure plane under direct shear. Since the direct shear strength of concrete is in the vicinity of 20% of concrete compressive strength, the former is unlikely and the concrete material is provoked to resist and fail under direct shear along the indicated failure planes.

Image 5

The optimum value of the angle is dependent on the type of concrete being anchored into and the interface friction that exists, however the value can be shown to be in the vicinity of 45^o.

If the state of the stresses is analyzed through stress transformations as shown in illustration – 1, it can be observed that an embedded anchorage with vertical sides fails when the interface bond t_1 is overcome by the pull P1. However as the sides begin to slope, new state of stresses are developed [t_2 and σ] that can balance the resistive components against the imposed pull action.

Illustration 1

The axial structural anchorage capacity of the design can be estimated as follows: If a 5 cm x 5 cm x 0,5 cm plate with 45° side slope angles is embedded in concrete, the shear plane area will be:

$$A = 20 \text{ cm} \times 0{,}5 \text{ cm} \times [1/\sin 45] = 14 \text{ cm}^2$$

If the Pençe® is embedded in concrete with cylinder strength of 30 MPa, the direct shear strength can be estimated to be 4 MPa. The total force along the perimeter that is developed in direct shear would then be:

$$F = A \times \text{direct shear strength}$$

$$F = 14 \text{ cm}^2 \times 40 \text{ kg/cm}^2 = 640 \text{ kg}.$$

Ignoring the direct tension anchorage provided by the holes, the amount of resistive force that is provided by a single anchorage embedded 5 mm within 10 mm concrete is quite sufficient for a façade application.

With a rod that is screwed on to the specially designed wedge plate of Pençe® a protrusion is obtained that can later be used to attach the plate to a parent structure.

Testing the Anchorage:

Having established a quantitative understanding of the anchorage elements, these elements can now be tested. Images – 6 and 7 show 10 mm thick concrete plate elements anchored with a 5 mm Pençe® embedment. Image – 6 shows a concrete plate supported by a single Pençe® under the action of 170 kg. Image – 7 is a 1 m2 concrete façade element under the action of a constant load of 250 kg which is the pressure value that could be generated on a unit area by hurricane force winds. Of course the wind pressure is not static and may act in a harmonic manner causing negative and positive pressures on the façade that may lead to concrete fatigue. Therefore, the capacity of a single Pençe® was determined for concrete fatigue strength of 30% of the static strength and with a factor of safety 3 for use in design. In other words, although the design wind pressure was accepted as 250 kg/m2 with a load demand of about 65 kg per Pençe®, the static strength of 640 kg determined for the particular configuration was considered to yield 192 kg under the action of harmonic façade wind exposure. A 1m2 façade element with count – 4

Pençe® per element was estimated to yield an ultimate strength of 769 kg/m2 with a factor of safety 3 that yielded a service fatigue strength of 256 kg/m2 which was larger than our design load.

Image 6

Image 7

Having established the conceptual framework for the anchorage element, different types of elements with varying protrusion numbers and lengths can be used depending on the design requirements as shown in image – 8.

Image 8

Following the easy placement of the Pençe® as shown in image – 9, the GFRC façade element becomes ready to be attached following the attainment of sufficient concrete strength.

Image 9

The lightweight Pençe® which is in the vicinity of 150 gr is easily supported by the viscous GFRC mix during placement and easily attains its position due to its symmetric shape. A complete 120 cm x 150 cm x 2 cm façade element with count – 4 Pençe® embedment is shown in image – 10 and a close – up of an embedded Pençe® is shown in image – 11.

Image 10

Image 11

Anchoring into a Structural Frame:

The last item of the façade, connection and supporting element system is the parent structural frame that supports the façade elements. Occasionally, façade elements are directly connected to the building main frame, typically at story slab elements or along the column heights. However, there usually is a lightweight structural frame between the façade elements and the building frame that support the façade elements. In terms of ease of constructability and placement, sometimes a lightweight steel frame is used to support and attach the GFRC façade elements to the parent structure. Image – 12 shows the galvanized St37 structural frame composed of 6cm x 6cm x 0,3 cm square steel elements.

Image 12

The GFRC façade elements require a special set of considerations during production, storage, shipment and placement. The tight tolerance requirements during placement and deformation considerations for the slender elements that also have not attained full strength during the stages of storage and shipment have to be considered carefully. During placement, the connection between the façade element and the supporting frame is achieved within a tolerance. The manufacturer must be aware of possible site conditions, especially if the supporting frame is not produced and installed by the GFRC manufacturer. In the event that the connection requirement are not met such that the connection within the façade ends up off – set from the part where it was intended to be connected, unconventional bridging schemes are devised typically on site that responds to short term solutions but which become frequently questionable in the medium and long term. Typical inappropriate site term solutions involve site welding and other fixing methods that have the potential to create undue stresses in the façade element. As a part of the study, a framing solution was devised where possible tri – axial offsets can be responded to by bolting in case of undue constructional occurrences on site.

A galvanized steel box frame that yielded approximately 4 kg of steel per m2 of façade was constructed as shown in image – 12. Connection elements were designed as shown in image – 13 where a slotted plate was attached to the frame over which a mobile slotted plate was bolted. The GFRC plates can either be supported from the horizontal elements or from the vertical elements or a combination of the two. The horizontal and vertical slots provided the respective tolerances which was 5 cm for the study. The vertical tolerance was provided by the protruding rod from the GFRC façade element.

Image 13

In other words, the union of the slotted plates and the Pençe® protrusion provided a connection that responded to possible tri – axial deviations of the connecting element positions. In the case that the protrusion did not meet an intended location as shown in image – 14 and ended up at an offset location with respect to the supporting element as shown in images – 15 and 16, the slotted plates provided the attachment given that the offset values were within the attachment tolerances which were provided by the length of the slots and the length of the protrusion.

Image 14

Image 15

Conclusion:

This study aimed to develop a simple anchorage element for thin concrete façade plates and a support mechanism that provided attachment tolerances for unforeseen site conditions. The anchorage element patented under the trademark Pençe® which means "claw" and the support frame patented under the trademark Cephetül® which means "façade tulle", provides a lightweight and an efficient support system for GFRC elements with the least amount of weight and thickness. Each Pençe® cost about 5 TL [2 Euro], each slotted plate about 1 TL [40 Cents] and the weight of the galvanized St37 Cephetül® is about 4 kg/m2.

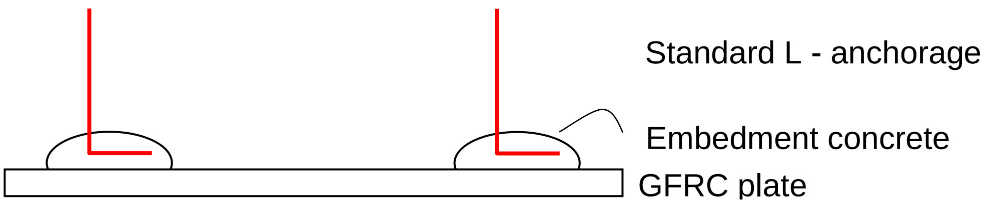


Image - 1

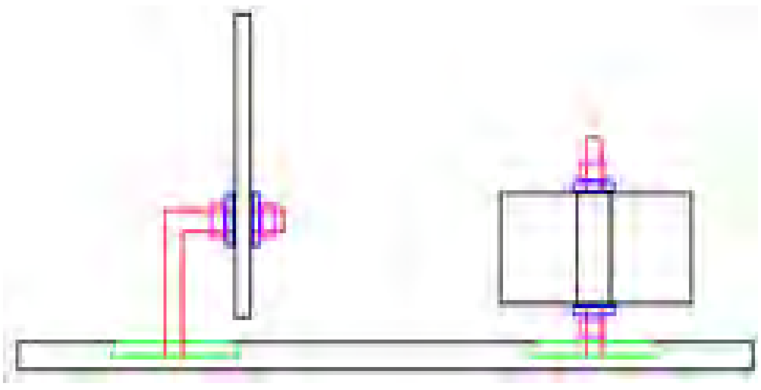
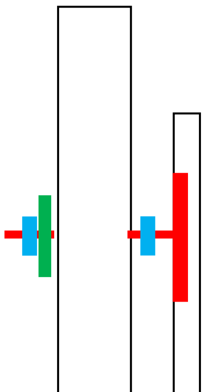


Image - 2



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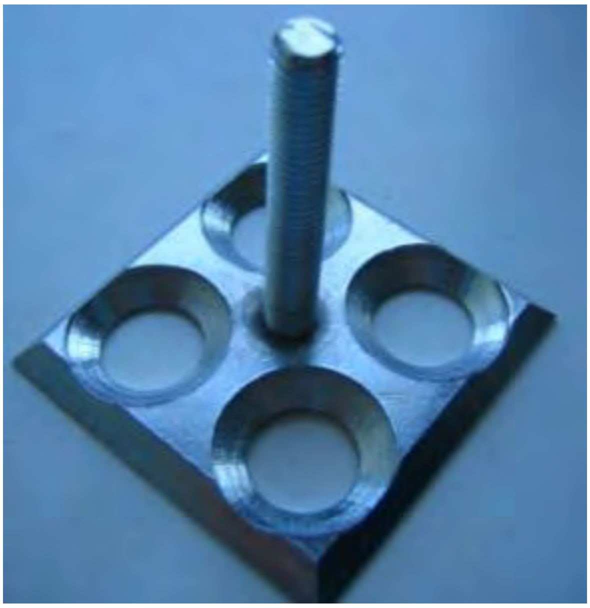

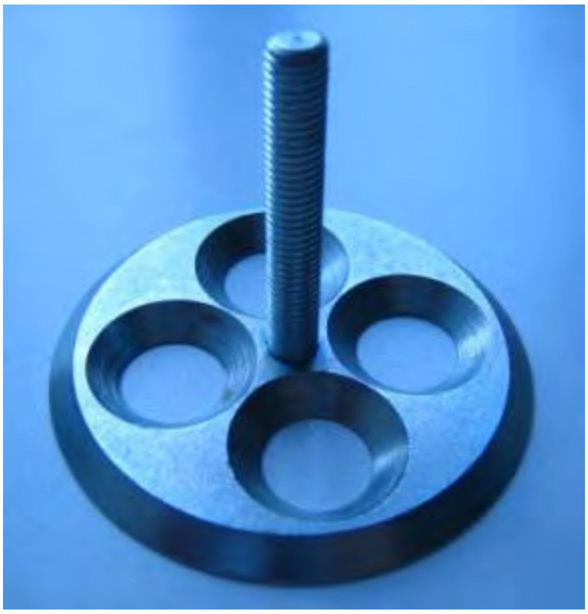

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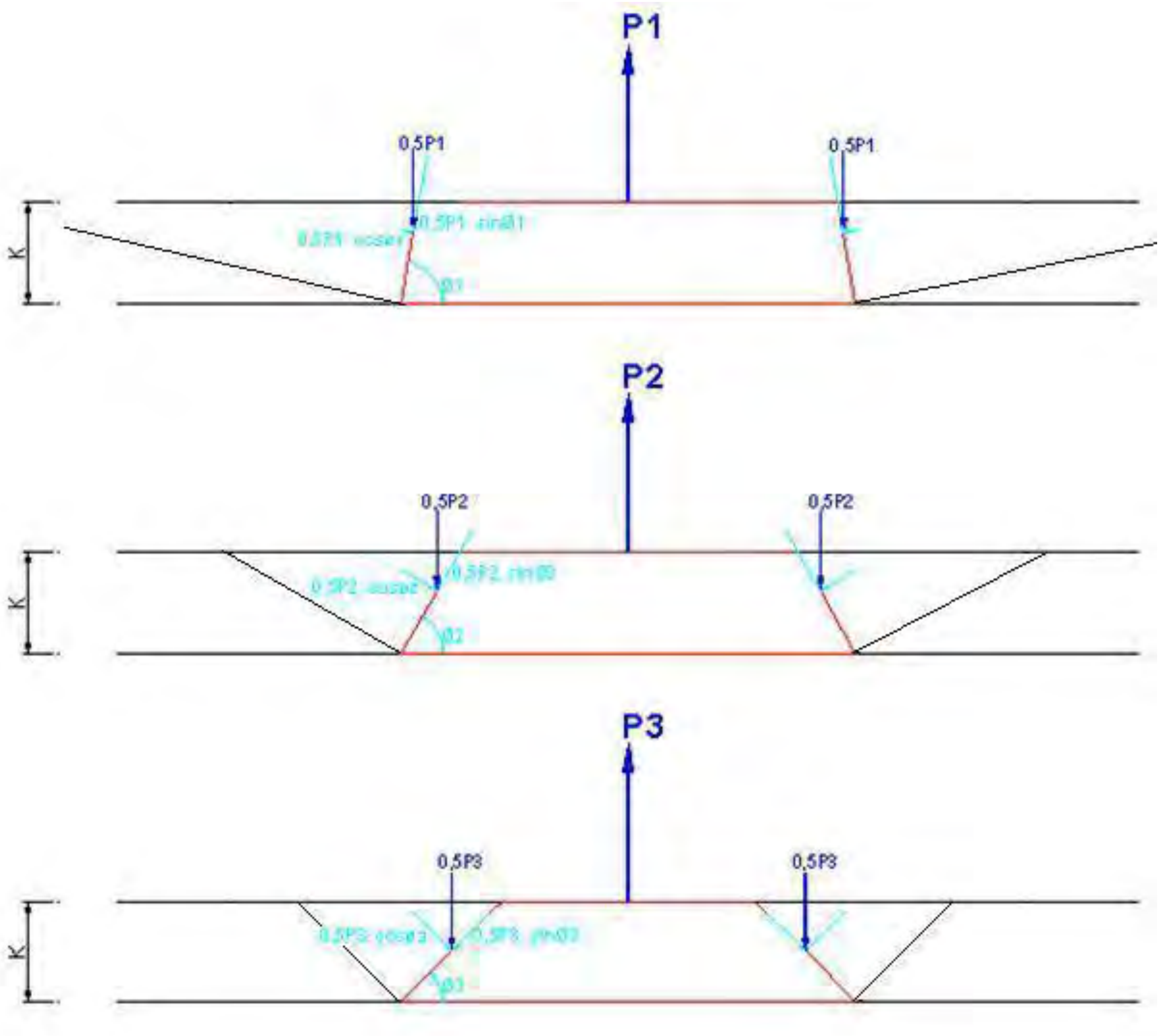
P1
0,5P1
0,5P1
K
P2
0,5P2
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K
P3
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Image - 5

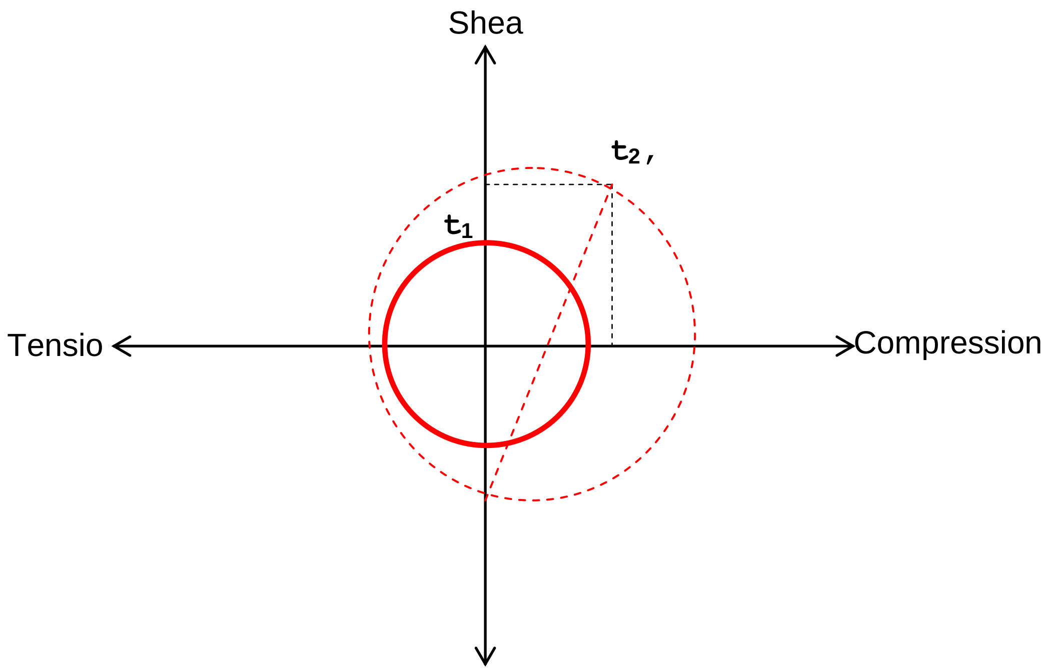
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Illustration – 1

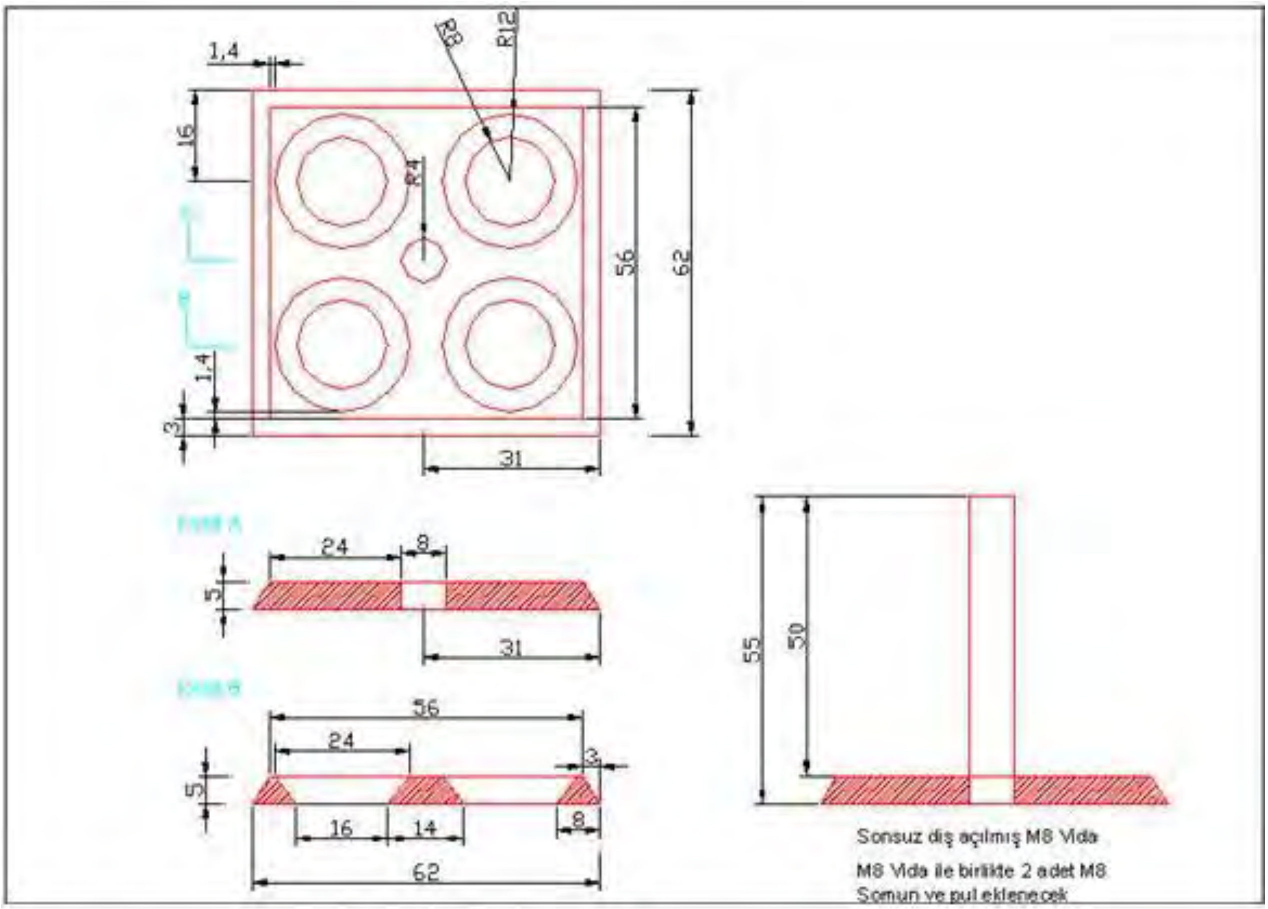


Illustration – 2

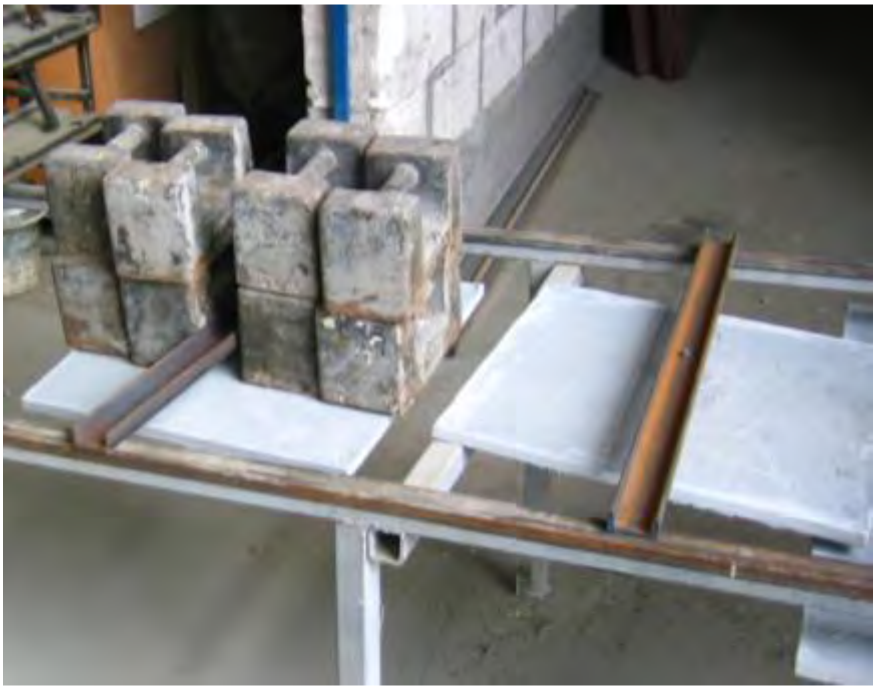


Image – 6

Image – 7

Image – 8

Image - 9

Image - 10

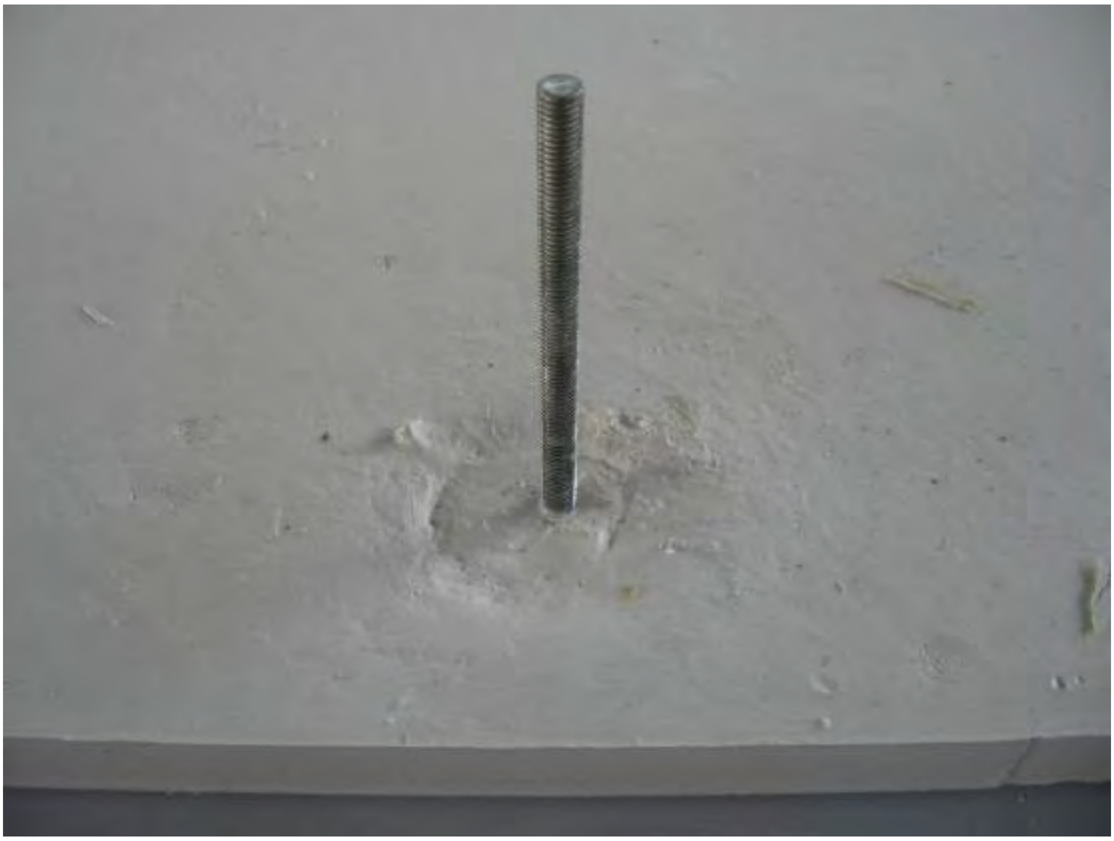
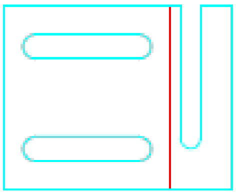


Image – 11

Image – 12

Image – 13

Image - 14



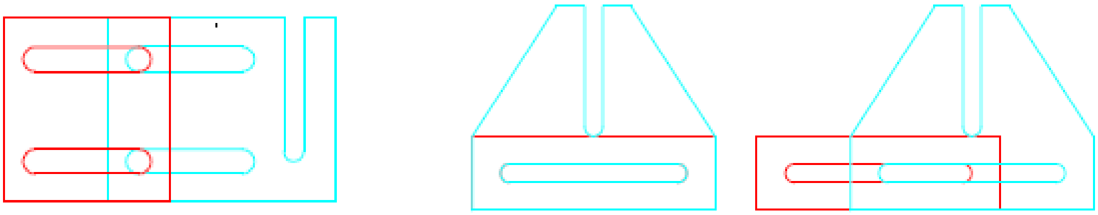


Image - 15