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The lobby façade of Iberdrola Tower

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Abstract

The Iberdrola Tower in Bilbao, with its 165 m height, is planned to be finished during 2011. The building, designed by Pelli Clarke Pelli architects, will have the shape of a triangular prism with curved sides. The lobby façade will be entirely enclosed by a sculptural glass wall forming a softly rounded triangle in plan and supported by vertical glass fins.

The design, simulation and testing of the glazed fins of the lobby façade will be discussed in the paper. Two different structural solutions for these elements will be compared, a plate girder and a lattice girder.

The variable surface curvature of the façade will be achieved by means of cold-bend insulating glass units.

Keywords: Structural glass, steel, cold bent glass

1. Introduction

The Iberdrola Tower, located in the city center of Bilbao, is currently in construction and will have a height of 165 meters with a stretched triangle shape. The office skyscraper, designed by Pelli Clarke Pelli architects, will have an enormous lobby entirely enclosed by a sculptural glass pavilion.

The complex changing curve of the wall façade will be achieved by means of cold bent insulating glass units with different inclinations. The structural support of the façade consists of vertical glazed fins 15 meters high and 0.5 meters deep spaced approximately 1 meter apart along the wall façade. The upper part is a cantilever of 5 meters above the roof line. These elements are designed and developed in collaboration with the architect, exploring for structural solutions which combine the use of two types of materials, glass and steel. The solution eventually adopted use a composite structure consisting of steel flanges bolted to a glass web.

The glass façade weight is transferred at the base of the fins while the wind loads are supported by the roof structure and the base. The roof structure, trapezoidal in section, consists of a tapered steel lattice designed with circular hollow sections ramped from Ø 323.9 to Ø139.7 mm. This spaced frame is fully supported at one end to the main concrete tower structure and 23 meters apart by two columns which define the main entrance to the building. After this point, the lattice is extended as a cantilever 15 meters to form the entrance pavilion.

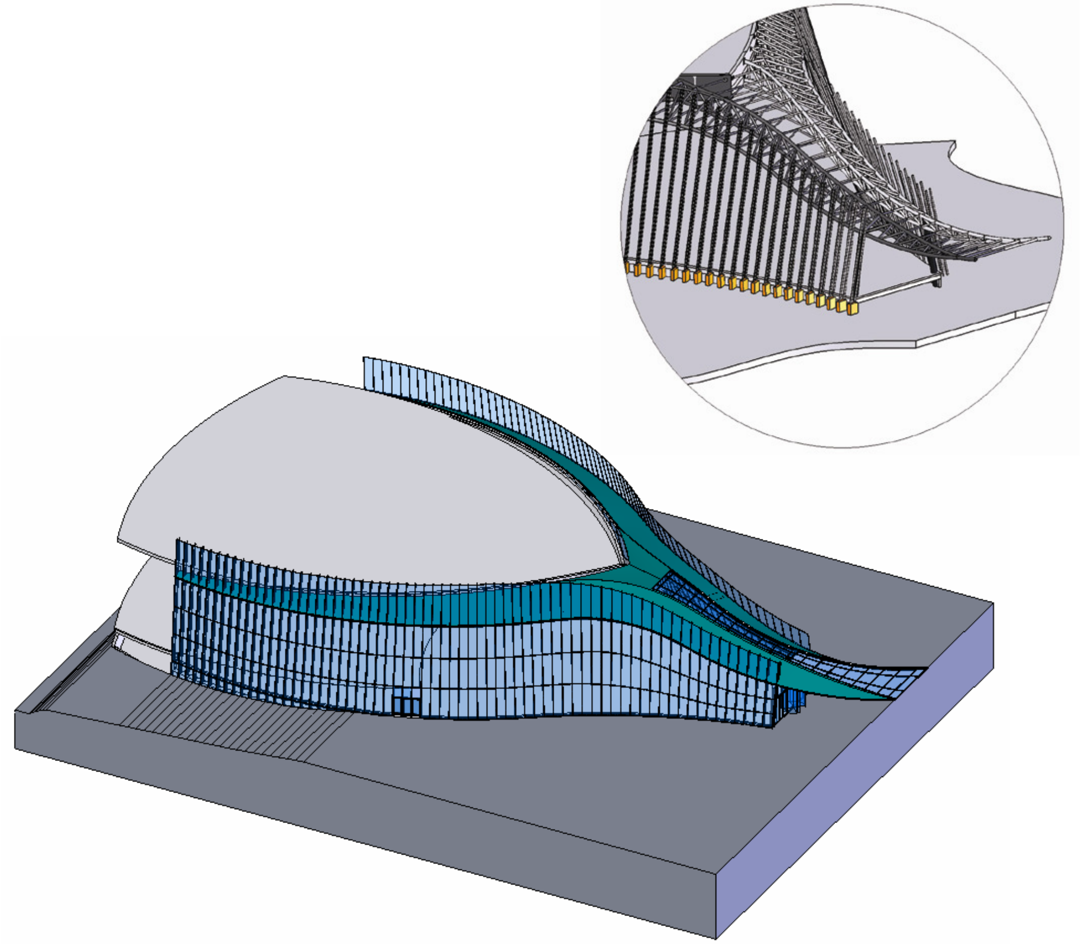

Figure 1. Sketch of the lobby

The present paper focus on the design, simulation and testing of the elements of the wall façade.

2. Glazed fins

The architecture tendency is the use of lighter and slender structures which implies the use of glass as structural element either alone or combined with other materials. Taking into account the brittleness behaviour of the glass, more accurate studies are required to achieve a satisfactory design, including the post-fracture behaviour.

2.1. Plate girder

The project structural solution to this type of element is inspired by the construction of built-up sections. The project glazed fin uses a composite section made of two semi circular solid steel flanges S355 with a radius of 60 mm pressed against an intermediate 10.10 toughened laminated glass by a high-strength friction grip with tension control bolts, grade S10T M20, located at 300 mm centers so that high friction forces are created at the contact surfaces. The structural behaviour of the glass fin is that of a composite beam**.**

The magnitude of the normal, shear and bending stresses that the friction grip connection can carry depend directly on the contact pressure and the friction material of the surfaces. Therefore, a high friction coefficient for the interlayer material between glass and steel is required. The friction grip connections are located close to edges in order to transfer effectively compressive and tensile bending stresses.

The loads in-plane are not transferred by bearing through the glass holes and less stress concentrations are present since the holes are oversized.

This glass fin design avoids the use of metallic connections between the glass panes which are 3 meters high, so a great transparency is achieved in the joints.

2.2. Lattice girder

The proposed glazed fin consists of two steel circular hollow sections Ø121x25 mm with internal glass plates connected to them by means of steel chromosome-shaped web members which allow the glass to work as a membrane shell. The structural behavior is that of a truss beam. The glass panes replaced the diagonal struts of a truss beam. In order to ensure a satisfactory bracing of the beam, internal glass pieces height must be reduced at half. The contact between the glass and the steel cross is performed by means of an epoxy resin which allows only the transmission of compression forces.

Figure 2. Plate girder and lattice girder proposed for the glazed fin

2.3. Comparative structural behaviour

The wind loads considered for the calculations were based on wind tunnel test data.
The deformation obtained for the plate girder is of 4.75 mm while for the truss beam is 7.4 mm. Differences in deflection are due mainly to the 34% reduction of weight of the parallel chords in the truss beam case, therefore to the reduction of the second moment of area, and to the contribution of the glass web members, which work as diagonals only in compression, to the deflection of the truss beam in contrast with the plate girder where shear deformations are negligible.

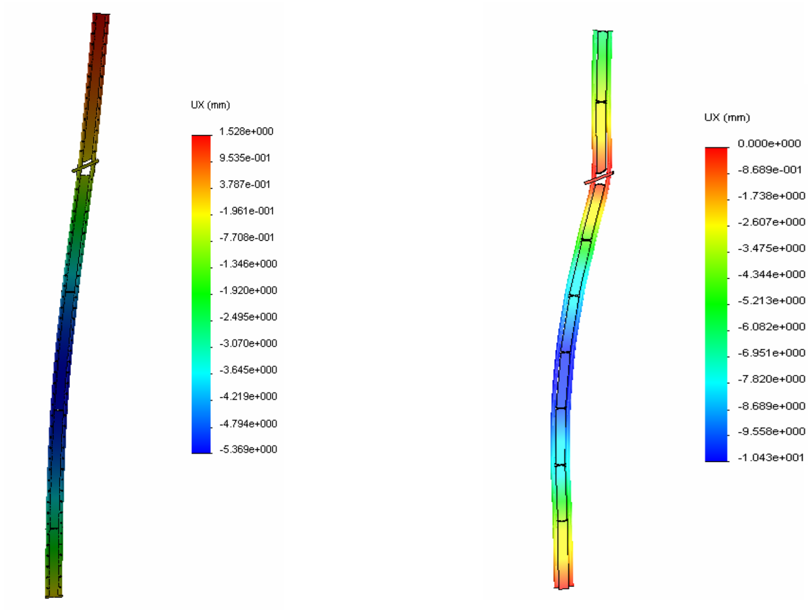

Figure 3 a,b: Plate girder deflection, lattice girder deflection

Like any tall and narrow structural member, the glass fins could buckle laterally if subjected to high negative pressures due to the compression of the back chord. So in order to ensure proper performance and safety a buckling analysis has been performed. The top and bottom connections have been designed so that they act as fork supports by means of stainless steel rods and steel clamps in order to prevent the lateral buckling. Likewise the top of the cantilever has been laterally restrained by a couple of stainless steel rods.

The weight support of the façade has also been considered since it produces compressive stresses which have the capacity to induce compression buckling of the glass and steel mullion.

It was observed that for both cases no buckling occurs at the ultimate limit state.

Concerning stresses, the steel part of the two fins is not highly stressed whereas the glass part is less stressed in the truss beam case principally due to the absence of holes.

2.4. Comparative post-breakage behaviour

The structural redundancy is higher in the case of the lattice girder since it has twice the number of plate girder glass webs. In comparative terms, it has been considered the collapse of one glass element of the composite beam and two glass elements of the truss beam.
Due to the chromosome-shaped rods in the horizontal glass joints, the response of the truss beam is more satisfactory with respect to deformations and shape stability whereas the girder beam have an abrupt change in the geometry of the chords although within the admissible values. As shown in the figure 4a,b, the displacements obtained in the central zone of the glazed fin have an increase of 66% for the composite beam and of 26% for the truss beam.

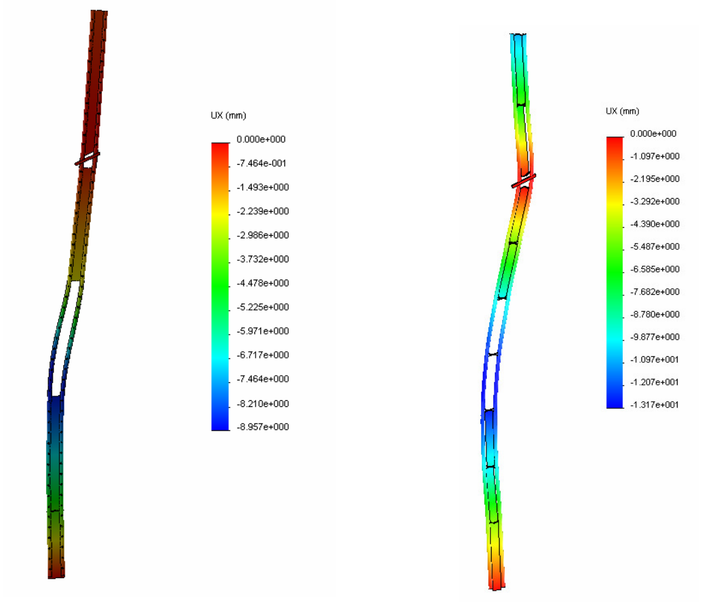

Figure 4 a,b: Plate girder deflection, lattice girder post-breakage deflection

The utilization factor of the plate girder steel chords has been nearly doubled but it is still lower than 100% whereas the resultant stresses in the truss beam are not so much higher than those obtained with any glass web broken. Stresses in the glass part of the composite beam increase considerably without exceeding the maximum allowable stress while for the truss beam case stresses do not increase significantly.

2.5. Fabrication challenges of the solution adopted

From the structural point of view the composite beam and the truss beam can be considered equivalent. Therefore, the choice depends exclusively on the aesthetic judgment. The solution finally adopted for the glazed fin was the plate girder one.

The contact surfaces of the clamp steel flanges must be accurately parallel and finely machined to avoid stress concentrations on the glass surface when the bolts are tightened which would lead to fracture. Therefore, strict fabrication tolerances are required. Bar straightness tolerance on both edge and flat is 1:1000 mm while twist tolerance is 1:3000.
The fabrication of the steel profiles consists of a hot rolling process where the input stock is shaped by two cylindrical and opposed rotating rolls, followed by a cold drawing process which allow to achieve the shape properties and the fitting accuracy required.
Afterwards, the special profile bars are submitted to a heat treatment, the normalization, in order to refine the grains which have been deformed through the cold drawn process and improve the ductility and toughness of steel. It involves heating the steel to just above its upper critical point. It is soaked for a short period and then allowed to cool in air. Finally, bars are straightened by means of press equipment.

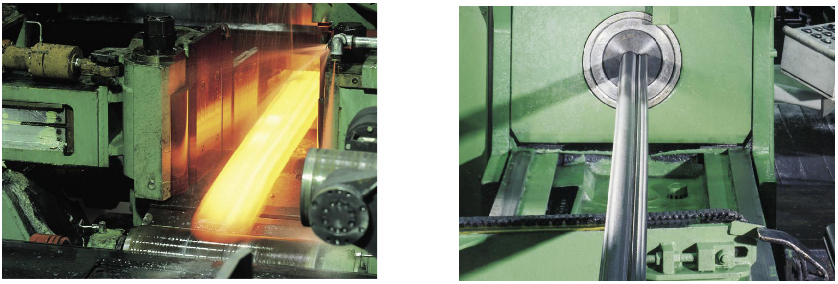

Figure 5,a,b: Hot rolling, Cold drawing

Concerning to the flatness of the glass, the maximum allowable values for total and local warping are 0.0015 mm/mm and 0.5 mm/mm respectively when measured according to the norm UNE-EN 12150-1.
The interlayer used for the extra clear tempered laminate glass is the SentryGlass(R) developed by Dupont. The main reasons for its use compared with the traditional PVB interlayer are its high transparency, superior post-breakage behavior and delamination resistance when exposed to the environment because of its not hygroscopic molecular structure.
The use of friction grip connections with safety laminated glass is technically very challenging due to the creep behavior of SentryGlass(R) interlayer. Therefore, in the areas of load transfer the SentryGlass(R) interlayer is replaced by an stiffer material such as aluminum. The main objectives in terms of fabrication is to ensure a good adhesion

between the aluminum washer and the ionoplastic interlayer and to avoid the formation of air bubbles during the lamination process in the autoclave. From the structural point of view, the post-breakage behavior in case of fracture of the two tempered glass plates is of special concern. The final solution adopted consists of replacing the SentryGlass(R) interlayer only in the zone near to the bolt subjected to compression . Traditionally, and angle of 45º is considered.

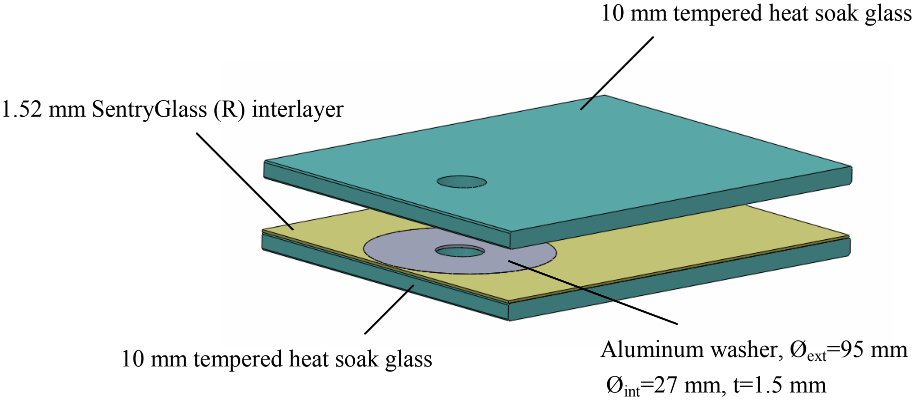

Figure 6. Glass web detail

2.6. Testing

The static friction coefficient of the interlayer material between glass and steel was determined by means of testing in order to verify the maximum shear resistance of the pretension bolts. The friction joint selected is composed basically by glass fiber, rock wool, modified phenol resin, rubber, and is used commonly for brakes.
The tests were performed following the principles of the norm ASTMD 1894 (Standard method for static and kinetic coefficients of friction of plastic film and sheeting). Prior to testing, the 5 samples are to be conditioned at 48 hours at 23ºC ±2ºC, with a relative humidity of 50 ±5 percent. Furthermore, the test specimen and the glass base are kept in touch during a minimum of 30 minutes.

The figure 7 shows the device used for the test. The resulting static friction coefficient was 0.32.

Figure 7. Device used to determine the static friction coefficient of the elastomer interlayer

It has been also tested the creep effect of the high tension bolted connection due to the elastomer material used as interlayer between steel and glass elements. This test allows to obtain the loss of the bolt pretension force with the time and determine if an additional tight of the bolts is necessary once the lobby façade is assembled.

For this purpose, two strain gages were mounted onto the bolt of the connection and connected to a Half-Bridge circuit. One gage is active and the second gage is placed transverse to the applied strain acting as dummy gage. The high-strength friction grip connection was loaded at 170 kN and conditioned at 25ºC in the climatic chamber during 190 hours. As a result, an exponential creep curve is observed with a decrease of the pretension force of 3.2%. Afterwards, the temperature of the chamber was increased at 60ºC, the maximum expected service temperature, during 1 day and the pretension force was decreased at 156 kN.

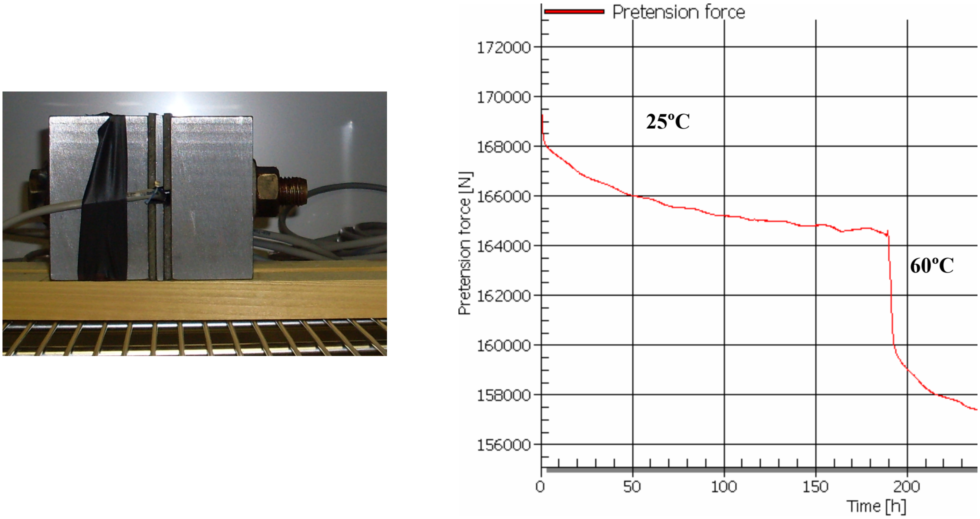

Figure 8. Creep Test

The structural behavior of the glazed fin will be assessed by means of a four point bending test over a 4 meters length beam, monitored with stress and deflection control over the metallic and glazed parts by means of strain gauges and a displacement transducer . This test will allow us to validate the FEA model calculations.

3. Cold bent IGU

3. 1. Description

The inclined and curved façade of the lobby has been performed by means of IGU's cold bent glass composed of two 6.6 high strengthened laminates. Calculations and testing has been carried out to obtain the stresses in the glass and the stress in the proposed structural silicone glazing. Due to the long rectangular shape of the glass panes, they are easily twisted on site at ambient temperature forcing one corner of each plane out-of-plane to a maximum displacement of 44 mm. Once adapted to the demanding geometry, the panes are secured with an attachment frame that is screwed to the glazed fin steel flanges and to the transom profiles. The panes of the façade have dimensions about 3.5 m by 1 m.

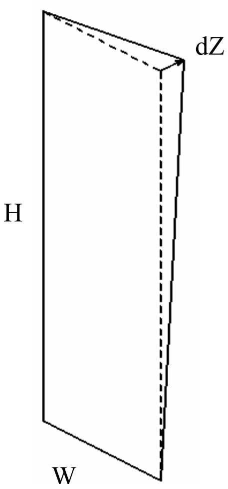

Figure 9: Twisted glass panel.

3.2. FEA analysis

A dynamic transient finite element analysis was performed by means of ANSYS software in order to determine the magnitude of stresses due to cold bent process. Glass is supposed to be elastic while the PVB plastic interlayer is considered viscoelastic. The thermal and time dependent behaviour of the PVB is described with the mathematical model of relaxation (generalized Maxwell model). The data made available by Dupont allows to compute the shear modulus at any time and temperature by means of a shift function (William-Landel-Ferry).

Immediately after bending, the laminate behaves monolithically since full shear transfer in the interlayer takes place. The maximum principal stress obtained is 4.4 MPa. The figure 10a shows the stress distribution in the plate applying the out-of-plane displacement of 44 mm at the right top corner during 3 seconds. However, one year later, a reduction of stresses is computed due to interlayer creep deformation. The figure 10b shows the maximum principal stress drop to the half approximately. Afterwards, a design load of 3.5 KPa and an additional climatic load due to the difference of height from installation and manufacturing place and temperature difference is applied to the model.

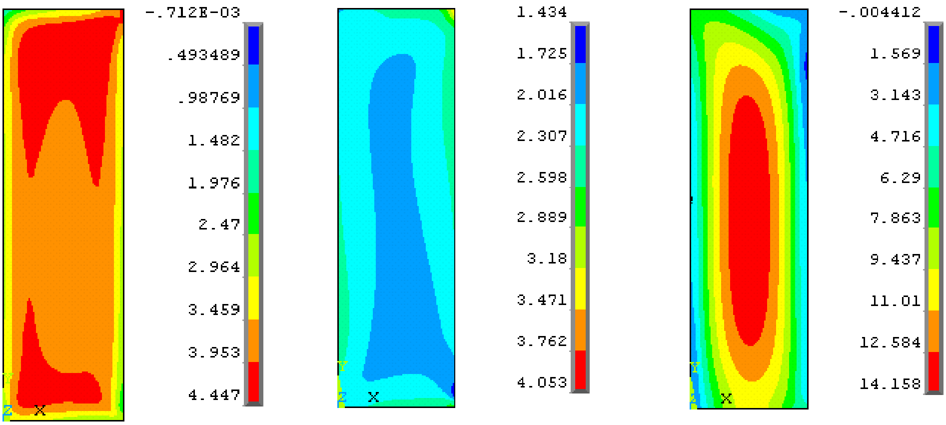

Figure 10 a,b and c: Maximum principal stress distribution after 3 seconds bending at 20ºC, after 1 year at 40ºC, after applying wind and climatic loads

From the results obtained, it was observed that the contribution in the global stress due to the cold bent process was not critical since the glass curvature is small.

3.3. Testing

The ageing resistance of the IGU's perimeter silicone sealing as well as the butyl joint, even when exposed to moisture and increased temperature over a long term is proved by testing. A long term test for moisture penetration through perimetral sealing in insulating glass units is being performed at the time of writing this paper on 15 standard size IGU cold bent units and 15 standard size IG flat units following EN 1279-2 in order to verify if different humidity penetration exists between them.

4. Conclusions

A comparison approach in the design of two traditional structural elements has been described. A built-up beam section and its truss alternative. What make these elements challenging in terms of design, manufacturing and safety is the use of a brittle material, such glass, in its composition.

In addition, the cold bent IGU glass skin in front of these steel and glass mullions makes the whole façade structure to be design-driven by the limited glass knowledge and experience.

Appropriate testing and structural redundancy are keys to asses the structural service behaviour and post-fracture stability.

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Structural engineering consultant:	IDOM	María del Mar Mayo
Project manager:	Technical office Iberdrola	Elena Lázaro
Design and construction:	Bellapart	Joan Colom, Sergi Plana, Carles Teixidor

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