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The ARoS Rainbow Panorama – Curved Glass as a Load Bearing Element

Switbert Greiner

ArtEngineering GmbH, Germany, www.greiner-engineering.com

A ring-shaped, tubular steel/glass structure resting on 14 columns, diameter 52m, is one main part of the art object "ARoS Rainbow Panorama" by Olafur Eliasson on top of the ARoS building in Aarhus, Denmark. The inner and outer walls with a total area of nearly 1,000m² are made of colored curved glass only. The glass walls have to carry dead loads, snow and especially wind loads and they have to withstand deformations of the system due to live loads and temperature. The paper at hand concentrates on the considerations of the structural design of this structure - the leading design ideas and its load bearing behaviour.

Keywords: curved glass, structural glass; structural design, load bearing behaviour

1. Task

On top of the ARoS Art Museum in Aarhus, Denmark, at a height of about 40m, the art object "ARoS Rainbow Panonorama" by Olafur Eliasson is currently under construction (see Figs.1 and 2). At present, the building is being prepared to serve as a foundation for the extra structures. The artwork consists of a large steel sphere and a ring-shaped walkway, diameter 52m, with glass walls at the inner and outer circumference. The glass walls (made of coloured curved glass) with a height of 2.80m and a width of 3.20m are part of the primary structural system. ArtEngineering GmbH was commissioned to undertake a feasibility study and to develop the structural concept. The paper at hand deals with the basic concepts of the structural design of the walkway, detailed considerations concerning the glass design can be found in [1].

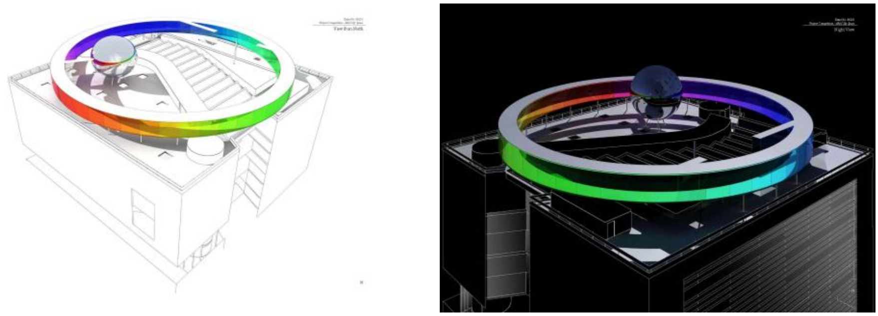

Figure 1: The ARoS Rainbow Panorama art object on top of the AroS art museum in Aarhus, daytime and nighttime views

1.1 The artist's vision of the walkway

The walkway is a tubular structure and can be seen as a steel-covered pedestrian bridge with glass walls on both sides, a roof out of steel plates and a box girder as the main bearing element (see Fig. 1). The walkway rests on columns - or almost seems to hover - 4m above the wooden floor of the roof. The glass walls are transparent and coloured in the colours of the visible spectrum like a rainbow. The ring is accessible for the museum's visitors, who can experience a panoramic view over Aarhus, which will be alienated by the colours. In the artist's vision, the walls are made solely using large curved glass panes. He stipulated that the use of any other load bearing elements or frames should be avoided (see Fig.2).

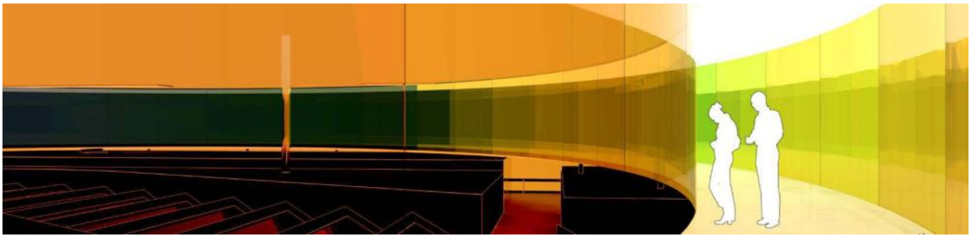

Figure 2: View of the inner appearance of the glass walls, no structural elements are in the inner and outer walls except the curved glass panes

1.2 Special conditions on the rooftop

The walkway rests on 14 columns, 4m above the top of the flat roof of the ARoS building, which is divided into two parts by an atrium (see Figs. 1 and 2). Above the atrium, the walkway spans 20m. The columns of the walkway do not match the columns and walls of the ARoS building at all. Therefore, a load distributing structure made of I-beams became necessary to transfer the loads from the walkway columns to points of the building's structure that are capable of conveying them to the ground (columns and walls). Since the building was not designed for such extra loads, reinforcements from top to bottom of the building became necessary. The structural height of the load distributing structure was very limited (all elements will be hidden under the final wooden floor of the roof) and its beams with maximum spans of 12m also have cantilevering parts. Therefore, one can say that the foundations of the walkway are interconnected springs, which, due to their flexibility, have a great influence on the design of the connection of the glass walls to the steel box girder and steel roof plate.

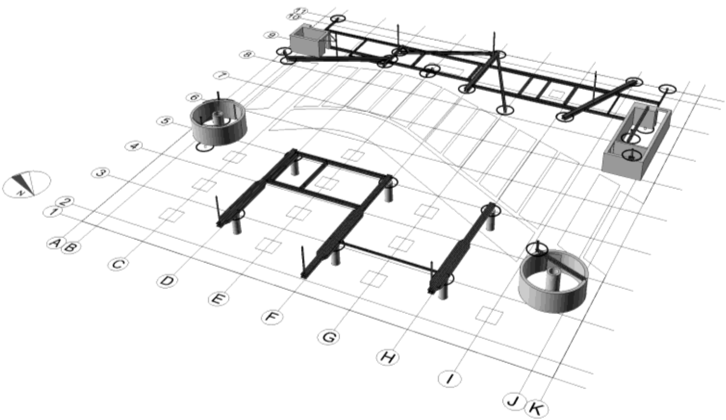

Fig. 3: The load distributing structure on top of the AroS building.

1.3 The design challenge

During the technical design of the walkway, we had to find a structure which is as light as possible due to the limited load bearing capacity of the existing building and we had to define a load distributing structure with a very limited structural height, but sufficiently stiff members.

The artist's stipulation for pure glass walls has been the most challenging aspect of the task because with this presetting, the glass walls became elements of the primary structure. They have to transfer considerable loads to the box girder and they are subjected to deformation loads from the walkway and the load distributing structure from live loads and temperature loads.

2. Solution

2.1. The glass walls as elements of the primary load bearing system

First basic design idea: Decoupling of the roof and walls from bending

The thought to use the total height of the section as statically effective is attractive (see Fig. 4 left, distribution of stresses/strains). A technical description of the walkway's section is given in 2.3 (Fig. 11), but it would not be possible to transfer the shear forces through the glass walls. They would break, even if it were possible to find a connecting method having the necessary bearing capacity. Therefore, we assign all bending and torsion to the steel box girder (see Fig. 4 right, distribution of stresses/strains). That means, we decouple the glass walls and the roof from the box girder. The chosen box-girder section is very stiff against bending and torsion; it becomes the backbone of the structure.

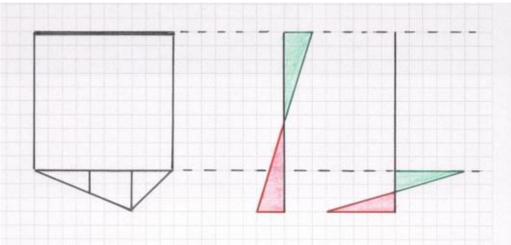

Figure 4: left: sketch of the walkway section with the triangular box girder, the glass walls and the roof plate;
middle: bending stesses/strains for the complete section;
right: bending stresses/strains if the box girder solely reacts to bending – this is what we wanted to achieve

Our first idea on how to realize this decoupling was to introduce expansion and compression joints in the roof and appropriate gaps between the glass panes (see Fig. 5). We checked this solution in a numerical model and it did work well. The glass panes inclined according to the bending of the box girder and the gap between them opened and closed as we expected. But again, we were challenged by the artist to find another solution because he did not like the visible radial joints in the ceiling.

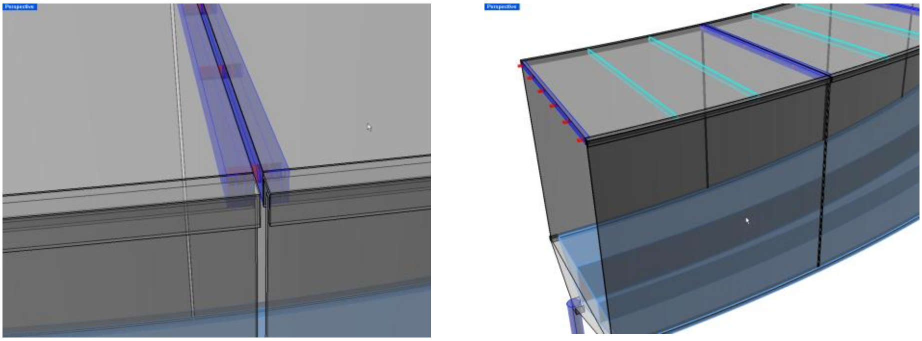

Figure 5: First concept of decoupling: extension/compression joints in the roof could be one method to exclude the roof and glass walls from forces out of bending.

Therefore we tried to decouple the glass walls with soft connections of the panes to the roof plate and box girder (see Figs. 6 and 10). This soft connection - soft against relative movements between the glass panes and the steel parts - also can decouple the roof and walls from the bending of the box girder as we proved with FE-models. Now the roof can be made as one simple ring-shaped plate element with a seamless ceiling. The clamp connection is soft for vertical movements of the glass, but it is fairly stiff against bending due to wind forces on the glass pane. This clamped support reduces the bending and bending stresses in the middle of the panes considerably.

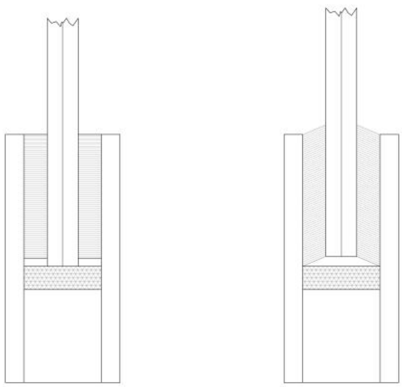

Figure 6:
left: Sketch of the connection detail for the glass panes at the lower and upper edge. The glass panes are glued into a steel clamp - which is fixed to the edges of the roof and the box girder – with structural glazing material.
right: The glass can execute relative movements to the steel parts, at the same time it is partly clamped.

Basic design idea II: In-plane action of the roof can activate an effective three-dimensional load transfer.
The roof is designed as a steel plate structure. Dead loads and snow loads are transferred to the glass walls by bending, but forces from wind action (on the upper half of the glass panes) shall be transferred from their origin by in-plane action through the ring to stiffer parts on the sides of the structure (see Fig. 9). Thus, we use capacities of the structure as

a whole three-dimensional object. The section (Fig. 11) does not need to work as a framework - this would generate bending moments in the glass panes that are too high.

2.2 How the load transfer works

Keeping the two basic design ideas in mind, it becomes clear, how the system works. Dead loads (roof and walls), snow loads and wind loads on the roof are transferred directly through the glass walls to the box girder (see Fig. 8, left). Live loads (3kN/m²) on the box girder are transferred directly to the columns (see Fig 8, right). Due to the decoupling of the bending deformations from the glass walls with the special steel/glass connection (see Figs. 7 and 12), the glass panes are not affected by bending deformations of the box girder due to live loads! From the box girder, all forces flow into the columns and then into the bearings of the load distributing structure (see Fig. 3).

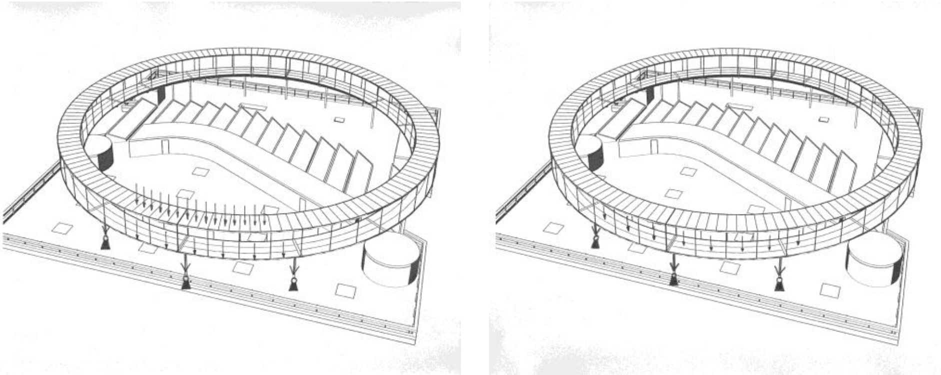

Figure 7: Transfer of vertical loads on the roof and dead loads from the glass walls; left: dead loads, snow loads and wind loads on the roof; right: live loads on the floor surface of the box girder

Wind actions are of major impact on the glass walls and add up to high horizontal reaction forces. The lower half of the wind forces is transferred directly into the box girder, the upper half is transferred into the roof plate. There, the forces flow via in-plane action to the stiff sides of the structure and from there through the glass panes into the box girder (see Fig. 9). This applies for the inner and the outer glass walls. Bearings in 4 stiff concrete parts of the AroS building are designed to take the horizontal forces from wind (see Figs. 4 and 9).

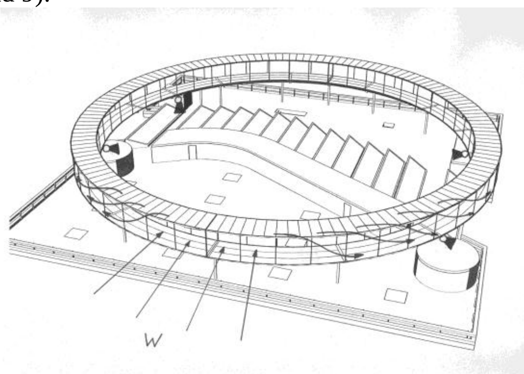

Fig.8: Transfer of wind loads; the wind loads act against the glass walls

Fig. 9 shows a section through the walkway and column. The inner accessible space is 3m high and 3m wide. In Fig. 10, the upper and lower detail of the special glass/steel connection is depicted in its conceptual design state. At present, the clamp is being tested.

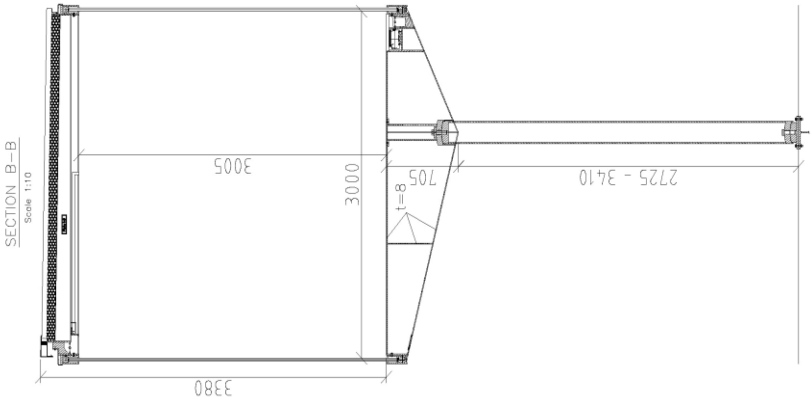

Figure 9: Section through the walkway with column

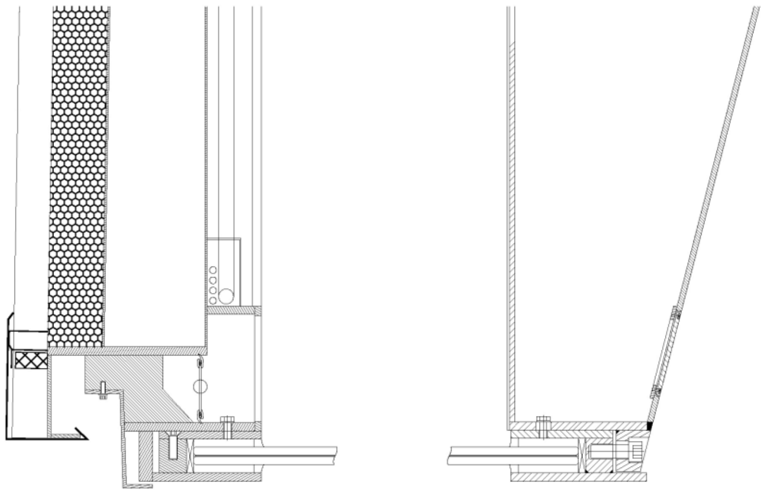

Figure 10: Clamping details at top and bottom

2.3 Conceptual design

The load distributing structure (see Fig. 3) is technically not ideal at all. Due to the very limited space we had to choose a combination of extremely low profiles to arrive at high masses. Esthetical considerations concerning the overall appearance of the art work lead to this solution.

The box girder is made of steel plates with a thickness of 8mm. It has an asymmetric triangular shape (see Fig. 11). At the inner edge of the floor there are openings for the ventilation which also contain special lighting. The closed section with its inner stiffener plates has a high bending and torsion stiffness.

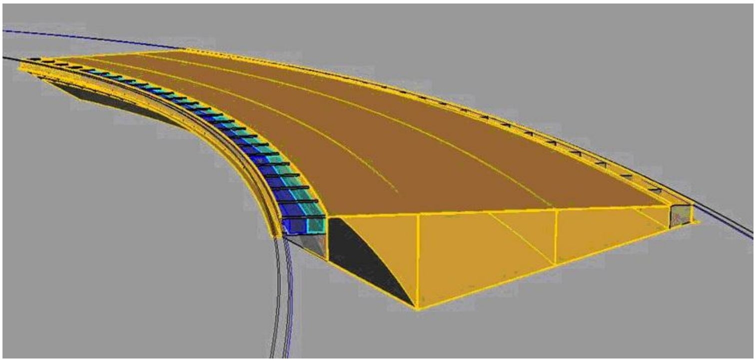

Figure 11: The steel box girder as the backbone of the structure

3. Calculations

3.1 Shell element model

To verify the design ideas of chapter 2, FE models have been elaborated. Using beam models of the total structure including all elements of the load distributing system, we calculated general forces, dimensions and deflections. For the quantitative verification of the decoupling method and the stresses in the glass panes, we created a large shell element model (>900,000 degrees of freedom, nonlinear analysis) of half of the walkway, together with relevant parts of the load distributing structure, because the low stiffness of the latter does influence the relative movements of the steel/glass connection considerably (see Figs. 13 and 14).

Calculations of the single glass pane showed that stresses under wind loads and all loads from the roof are in a moderate range, even when we neglected the compound effect of the lamination (this makes sense, because the coloured glass could warm up under sun radiation and the PVB foil could become too soft to guarantee the compound effect). The shell element model proved that the inevitable deformation loads from the box girder affect the load bearing capacity of the glass panes only to a very small extent.

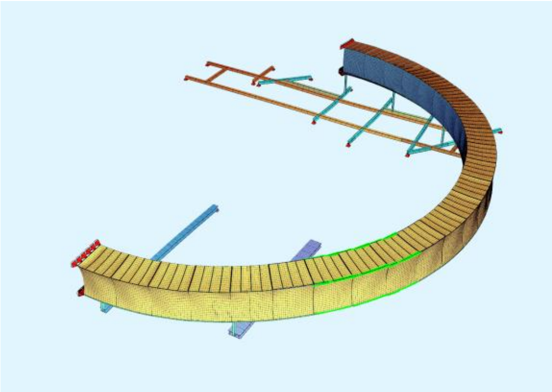

Figure 12: Shell element model of one half of the walkway under live loads, wind loads and snow loads (scaled up deflections)

3.2 Relative displacements in the steel/glass connection

For the clamp design one needs maximum values of the relative movements between steel and glass in the bonded connection. These can be derived from the shell element model, where the clamping detail has been represented by a system of auxiliary small beam and spring elements with a vertical orientation. The beam elements, which connect the steel and glass parts, have been modelled as free of normal forces, such that both parts can slide relatively in a vertical direction. Spring elements simulate the shear stiffness of the structural glazing material in the connection. Fig.13 shows the deformations of the system under maximum loads. The vertical gap between two adjacent glass panels - which will be closed with silicon - has been modelled as an open slot.

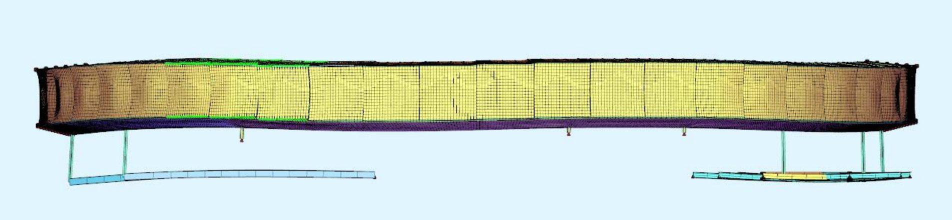

Fig. 13: Shell element model of one half of the walkway under maximum loads, displacements are scaled up

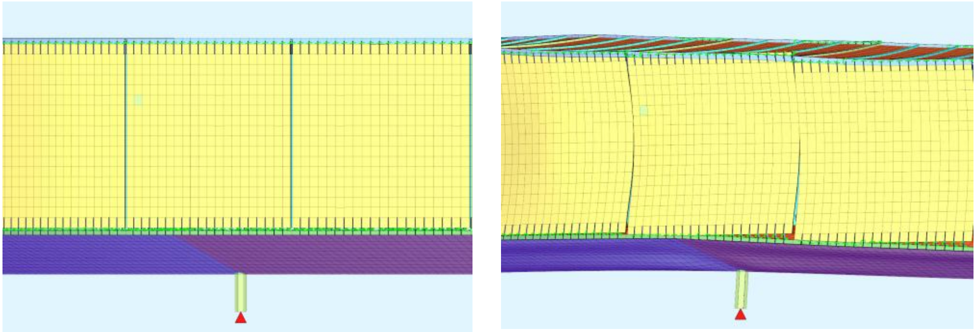

Figure 14: The soft connection between steel and glass under action, displacements are scaled up

Close to the short column on the left side and at the beginning of the big span, we have the biggest inclination of the deflection curve and thus the highest relative movements between steel and glass. This part is shown in detail in Fig. 14, being unloaded on the left picture and loaded on the right one. One can clearly see how the system reacts: The box girder deforms independently from the glass panes, which remain in a vertical position. The shear force due to bending is not transferred to the glass walls as we did aspire. Absolute values of the relative movement are shown in Fig. 15. They deviate between -3mm and +3mm. That means that the steel/glass connection should allow at least 6mm of shear movement.

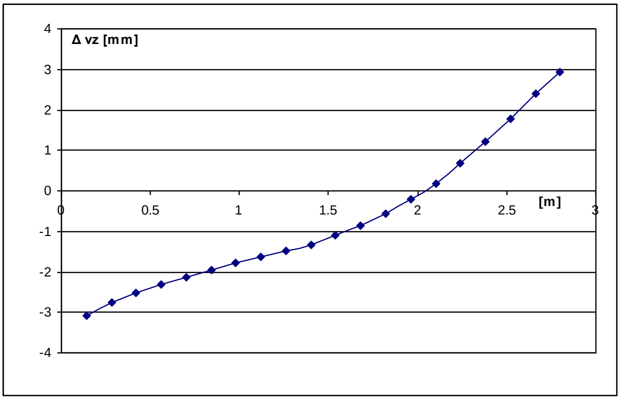

Figure 15: Relative movements Δvz in the steel/glass connection; abscissa: horizontal extension of the pane; ordinate: relative vertical monements Δvz in [mm].

3.3 Summary of technical data

Glass:

Total area of glass wall982m²

Type and thickness of glass:	2x12mm, toughened
Number of glass panes:	2x58 pieces
Size of single outer pane	3.20x2.80m²
Lamination:	2 clear PVB foils, 0.38mm, 4 coloured PVB foils, 0.38mm (Vanceva colour system)
Structural sealant material in clamp:	Dow Corning DC993, 2x12mm thickness
Glass tests:	impact tests with soft and hard body of the clamping detail

Steel:

Load distributing structure:	variyng I-beam sections and combinations, 95t
Walkway box girder:	52m outer diameter, 85t
“ columns:	steel tubes 244.5mm diameter, 3t
“ roof:	20t

4. Conclusion

The use of glass as a load bearing material depends very much on the structural design. Only successful team play between all members of a structure can guarantee success. The paper shows that it is possible to build the described walkway structure with pure glass walls even though the structure is heavily loaded and has big spans and is supported by a soft load bearing structure, which deflects considerably under live loads. This is achieved by decoupling the glass walls from deformations of the walkway due to live loads and the activation of a three-dimensional flow of forces under wind loads. The decoupling is provided by a special steel/ glass connection. And the wind forces are transferred to the stiff sides of the ring via the activation of an in-plane action in the roof plate.

5. References

[1] Henriksen, Thomas; Greiner, Switbert, AroS, *Your Rainbow Panorama by Olafur Eliasson* (GPD 2009).

AROS, Your Rainbow Panorama by Olafur Eliasson

Thomas Henriksen
GlassDesign Ehf
Gullengi 6, 112 Reykjavik, Iceland

Dr. Switbert Greiner
ArtEngineering GmbH
Bussenweg 4, D-70771 Oberaichen, Germany

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1: Curved glass 2: Coloured interlayer 3: Structural glass

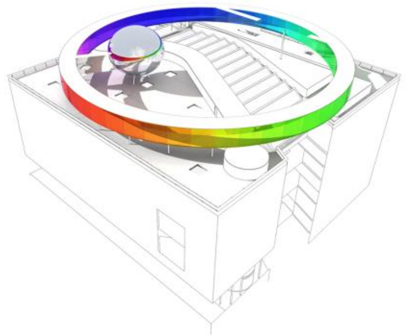
Abstract

Studio Olafur Eliasson has designed a panorama walkway placed on top of the ARoS art museum in Aarhus, Denmark. This paper is a case study for the design of the curved load bearing glass walls. The walkway is 52m in diameter, consisting of 58 different panels. The curved glass panels are 3.2m high with a width of 2.8m. The panels support the roof and provide stability for the walkway. Each panel is laminated with a different colour of interlayer which, seen together, represent the colours of the rainbow. The principles of the technical design concept, e.g. the interaction of the steel structure with the glass panels, have been investigated and verified with different FE models. For the design choice of the glass panels, FE models and available design methods have been used, with personal safety, fire issues, load bearing capacity and the glass manufacturer’s capabilities being the main dimensioning factors.

Introduction

The Rainbow Panorama walkway is a part of a work of art by the artist Olafur Eliasson. The work of art is going to be placed on top of the ARoS art museum in Aarhus Denmark. GlassDesign has assisted ArtEngineering in the design and selection of the glass. ArtEngineering has performed the main engineering for the overall structure.

The walkway consists of an inner and outer glass ring, resembling a rainbow. Each panel in the walkway has its own transparent colour. The walkway is 52m in diameter and is elevated 4 metres above the roof level of the museum. The glass is the primary structural element supporting the roof of the walkway, i.e. the glass is acting as a structural element. The glass is curved and consists of two leafs of 12 mm thick glass laminated together. The glass panels are 3.2m high and have a width of 2.8m, the total number of panels in each ring is 58. The glass is coloured by using a Saflex interlayer with the Vanceva colour system, and has up to 4 different coloured layers per panel to achieve the right tone. Rendering of the walkway placed on top of the ARoS building is shown in figure 1 and figure 2.



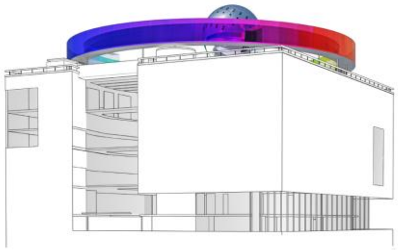


Figure 1 and 2 Renderings of the walkway.

Design thoughts for the steel/glass interaction

The walkway consists of five main structural parts, shown in figure 3 and figure 4: The walkway's roof, the structural curved glass walls, the steel box girder as the main part, the 14 columns which elevate the walkway four metres above the roof level (maximum span 20m), and the load distributing beam system, which brings the loads from the walkway columns to the columns and walls of the ARoS building.

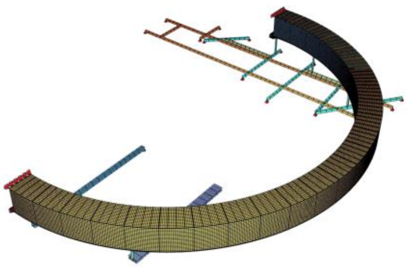


Figure 3 FE model of walkway structure with load distributing beams

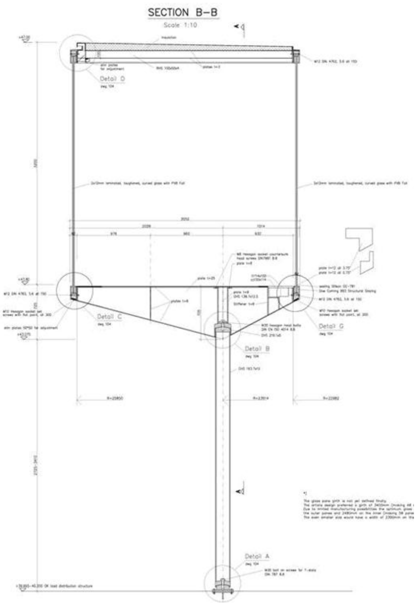


Figure 4 Section of walkway

Without special means, the complete section of the walkway (box girder, glass walls and roof) would act as one beam section with the glass walls as webs. This would not work, because the inner forces due to all the loads and displacements of the steel structure cannot be transferred by the glass and its connections to the steel. The first basic design idea was to decouple the glass as much as necessary from the steel, without neglecting its primary function as a structural element for the wind loads and loads from the roof.

The second design idea was to build the roof as a stiff plate element which transfers wind loads on the glass walls from their origin to the much stiffer sides of the structure.

The dead load and snow load from the roof and the self-weight forces from the glass panels are transferred directly down to the box girder through the glass panels, which only results in small stresses.

The dimensioning load for the glass is the wind load. Its lower half is transferred directly to the box girder and the upper half to the roof plate of the walkway. The glass panels act locally more or less as beam elements, even though there is also a membrane effect. The roof plate acts like an arch and transfers the local wind loads to the sides of the walkway, where they can be transferred down to the box girder by relatively small shear and normal forces through the glass.

The live load on the box girder (3 kN/m²) is transferred directly by the box girder to the columns. This results in deformations which must not be transferred to the glass panels. To avoid this, a special connection becomes necessary, a sketch of the detail is shown in figure 5. The same connection is used for the glass fixings to the roof and to the box girder. This connection is soft for vertical movements, still capable of transferring the (vertical) normal forces, but it is stiff according to the bending of the glass from the lateral wind forces. This is the core element of the glass/steel structure. The connection is being finalised by the facade contractor according to the principle shown in figure 5.

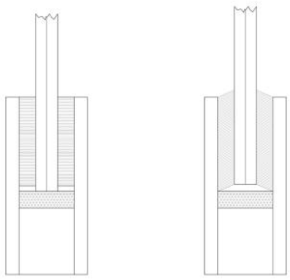


Figure 5 Schematic illustration of steel glass/connection which allows vertical movements of the glass relative to the steel.

Verification of the design

To verify the design ideas, quantitative finite element models have been worked out. The overall functionality has been tested in a large FE model (>900 000 degrees of freedom, nonlinear calculations) of one half of the ring structure, together with the columns and the beams of the load distributing structure. In this model, all surfaces from the roof, the glass panels and the box girder have been modelled with a fine net of shell elements, and the connections between steel and glass with spring elements. Thus, it was possible to study the behaviour of the combined structure under realistic conditions.

Figure 6 shows the overall deflections (scale is exaggerated). One can see that the box girder does not transfer its deflections to the glass panels. The panels remain in a vertical position. They do not transfer shear forces from the box girder bending to the walkway‘s roof. On the contrary, they move slightly up and down, which means that they decouple the walkway‘s roof from the box girder. The vertical glass joint has to allow a relative movement of the adjacent glass edges.

Figure 6

Design of the glass

The idea of using glass as a structural element to carry a roof structure has been used on several buildings in recent years. Recently the crypt entrance to St. Martin in the Fields in London has been completed. (Designed by Eric Perry and engineered by Arup). Using glass as the only load bearing element to support the roof, means that the glass has to be able to transfer vertical loads as well as the overturning moment to ensure stability of the glass and the roof. In the case of the Rainbow Panorama, then the local municipality requested additional requirements to be fulfilled before allowing the use of structural glass as a primary load bearing material, besides the capability of supporting the roof and providing stability to the structure, listed in (1) – (4).

The glass has to be safety glass and fulfil class 2B2 in EN12600 [1]. (1)

The glass has to fulfil the requirement of a class A1 material. (2)

The load bearing elements in the walkway have to resist a fire for 60 minutes (R60), and at the same time not allow smoke into the walkway. (3)

The glass has to have sufficient strength to accommodate the loads. (4)

As shown in figure 1 then the walkway is situated on the top of the building. The building is squared with a side length of 52m. The new walkway has an outer diameter which is the same as the building. This means that in four places, the outer glass ring in the walkway will touch the edge of the building. Therefore a fall from the walkway in case of glass breakage would be approximately 40 metres. The rest of the walkway is elevated 4 metres above the roof terrace.

This level difference between the walkway and the roof and ground level requires that the glass is classified as a safety-glass according to the local building regulations. The building regulations refer to a local standard DS/ INF 119 (2006) [2], which is based on the clarification system used in the EN12600 [1]. This requires that the glass as a minimum is laminated (class B), because the level difference between the walkway and the roof terrace is more than 0.5m.

Regarding the fire, then requirement (2) can be fulfilled. The glass is a class A1 material and is not flammable and will not contribute to a fire. However, requirement (3) can only be met if a fire insulating material is used or else the glass would loose its integrity if the glass is subjected to direct flames, and can therefore not fulfil the R60. This would consequently make it difficult to use coloured interlayer in the glass and is not an acceptable solution to the Studio Olafur Eliasson. Instead a solution was made where the probability of a fire, which could give direct flames on the walkway, was investigated. It was shown that by adding sprinklers to all buildings placed on the roof and additionally ensuring that all the material used on these building is not flammable, then a probable fire would not have a magnitude which would result in direct flames on the glass. The hot fumes from the flames would still have a temperature which would exceed 350°C when it touches the glass. Therefore the glass needs to be heat treated, toughened or heat strengthened. To avoid expensive fire tests then information from fire tests from earlier glass projects where used. This showed that 2 x 12mm heat strengthened glass placed in a roof would accommodate gas fumes op to 450°C before the glass laminated starts disintegrate and fall down. Two layers of toughened glass could potentially loose it post fracture integrity because of the break pattern. Therefore 2 layers of heat strengthened or a mix of heat strengthened or toughened glass would have the best performance in case of a fire under the walkway.

The structural requirements to the glass have been found by using Eurocode 1, 2005 [3]. The loads which is applied to the dimensioning glass pane is the following, vertical loads are disregarded:

> Wind load: 1.59 kN/m2 (pressure) and 1.15 kN/m2 (suction) applied perpendicular to the glass surface.

The stress in the glass is calculated by using a FE-model. The glass panes are calculated as simple supported in top and bottom. In the analysis a single leaf of 10 mm and 12 mm glass is considered. This is because of the coloured interlayer, which can accumulate heat so that the interlayer losses it shear transfer capabilities. The maximum stress in the glass from the analysis is 23.3 N/mm2. The stress plot for the 10mm curved glass is shown in figure 7 and the 12mm curved glass is shown in figure 8.

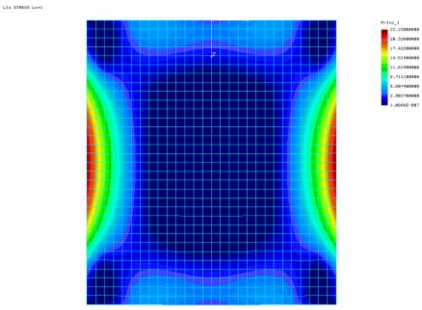


Figure 7 stress plot of 10mm curved glass, maximum stress is 23.3 MPa

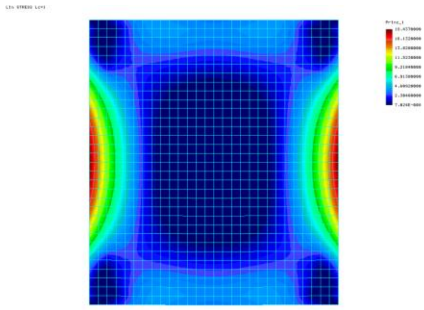


Figure 8 stress plot of 12mm curved glass, maximum stress is 18.4 MPa

The allowable design stresses for the glass have been determined according to prEN14373-3[4], Nov 2005. For toughened glass the allowable stress is determined to the following:

$$f_{eg;d} = f_{g;d} = \frac{k_{\mathrm{mod}}\, k_{sp}\, f_{g;k}}{\gamma_{M;A}} + \frac{k_v\left(f_{b;k} - f_{g;k}\right)}{\gamma_{M;V}} \qquad (5)$$

$$k_{\mathrm{mod}} = 1.0,\ k_{sp} = 1.0,\ f_{g;k} = 45\frac{N}{mm^2},\ \gamma_{M;A} = 1.8,\ k_v = 1.0,\ f_{b;k} = 120\frac{N}{mm^2},\ \gamma_{M;A} = 1.2$$

$$f_{eg;d} = f_{g;d} = \frac{1.0*1.0*45\frac{N}{mm^2}}{1.8} + \frac{1.0*\left(120\frac{N}{mm^2} - 45\frac{N}{mm^2}\right)}{1.2} = 87.5\frac{N}{mm^2} \qquad (6)$$

For Heat Strengthened glass the allowable stress is determined to the following:

$$f_{eg;d} = f_{g;d} = \frac{1.0*1.0*45\frac{N}{mm^2}}{1.8} + \frac{1.0*\left(70\frac{N}{mm^2} - 45\frac{N}{mm^2}\right)}{1.2} = 45.8\frac{N}{mm^2} \qquad (7)$$

Comparing the allowable design stresses with the calculated stresses from the FE analyses, then two 10mm heat strengthened curved glass would be sufficient. In the analysis of the 12 mm glass then the stress is 18.5 MPa, which is significantly lower than the 10 mm curved pane. This is mainly due to shell effects. However it could be difficult to acquire a 12mm heat strengthened curved panel, therefore a 10mm heat strengthened curved panel may be the only alternative, if heat strengthened glass is going to be used instead of toughened glass.

Selection of the glass

In the selection of the glass composition then additional parameters than the above mentioned needs to be taken into account; the usages of coloured interlayer, post breakage integrity and production capabilities.

Using coloured interlayer in the glass means that the interlayer could potentially accumulate heat. Since the top and bottom of the panel are hidden in a frame, then there could be a risk of thermal breakage in the glass if annealed glass is being used. This together with the fire restrictions means that annealed glass cannot fulfil the requirements; therefore the glass needs to be heat treated.

If two leafs of toughened glass is considered, then experience from other structural glass structures has shown that the usages of two layers of toughened glass can collapse from its self weight if both panes are broken; therefore a requirement for the usages of glass with different break patterns is preferred. This is described in the Norwegian standard NS 3510, 2006 section 4.5.4 page 6 [5]. If both layers are broken then the different break patterns keeps the glass intact, and will have sufficient capacity to work as a barrier against impact. If two leafs toughened glass would be considered because they would be kept in place by structural silicone, then hot fumes from a potential fire, could reduce the silicones stiffness, and the glass could fall out, therefore this solution is not considered as optimal.

The suggested glass composition in this situation is a combination of heat strengthened glass and toughened glass. The heat strengthened shall be placed on the inside of the walkway to prevent the glass from breaking if small impact damages are made to the glass. The preferred solution is 12 mm heat strengthened + 12 mm toughened glass laminated together with coloured PVB interlayer’s.

However geometric differences in the production of the curved toughened glass and curved heat strengthened glass may change this, so that either 2 leafs of heat strengthened glass or two leafs of toughened glass have to be used. This is being investigated at the moment.

Optical quality of glass

The optical quality of the glass is in focus because the glass is used as a part of an art piece and is a panorama viewpoint. Curved glass have been seen to have bad optical quality, therefore it has been specified that the glass supplier can only use a continuous mould less furnace for heat treating and curving of the glass, preferably with double convection technology. Additionally then the furnace has to be accepted before the glass supplier is chosen. A full 1:1 mock-up of the glass pane has been requested for approval before commencing with the entire production.

Testing of the glass

To ensure the right performance of the glass then the curved glass is being tested according to CWCT technical note TN42 [6]. Four specimens are being tested. The specimens are being tested for soft and hard body impact test, and a wind load test, by using sandbags as load on the glass. The glass is tested for wind load, with both leafs intact, one leaf broken and both leafs broken. The test criteria is that the glass do not collapse

Conclusion

The Rainbow Panorama walkway have been designed with glass as a primary structural element and at the same time using heat treated glass with a size of 3.2m x 2.8m, consisting of 12mm heat strengthened + 12mm toughened glass. The usage of structural glass has been accepted by the municipality of Aarhus commune. The walkway is expected to be finished in spring 2010.

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