Glass Stairs in Venray

Constructing Glass

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Making stairs completely out of glass is difficult. That is one of the reasons why there are not many of these. Having glass steps is not too uncommon, but stairs of which the complete supporting system is also made out of glass is unique. The engineering firm Verhoeven & Leenders from Volkel, nearby both Eindhoven en Den Bosch, dared to give it a shot. To make the design even more challenging the stairs is located in a private spa, causing the climate to be warm and humid. The best known glass stairs, are the ones in the Apple Stores around the world, these stairs is also from which they took inspiration.

To fit more in the design of the spa the client initially wanted all elements to be round. However, the radius of the column would become too small for glass to be bend practically. Therefore, the column ended up with a squared cross section, with the consequence that the steps could not all be made the same. Almost each step would have a different angle to a straight plane of the column. To reduce the cost down as many as possible it was attempted to make as much steps as possible the same. However, it still meant that half of the steps are unique. Besides the column and the steps, the railing is also made of glass and is part of the supporting structure. The steps must be supported on both sides to prevent too large deformations in the steps. To make the handrail also part of the supporting structure for the steps, three L-shaped beams are connected to the column. One of these beams is shown *Figure 1*. These L-shaped beams are connected to the corners of the column, to ensure an equal vertical loading on each beam. Therefore, the dimensions of the beams are all the same, only the length of the part connected to the column varies.

Figure 1: Suporting L-shaped beam of the side rail.

Taking a closer look at the materials used, two different types of laminated glass can be distinguished. In the handrail and the column, a polyvinyl butyral (PVB) interlayer is used as it allows for some flexibility. This will not be an issue as the loads are applied in the longitudinal direction, thus due to the nature of the loading and the connection the glass layers already work together. The laminated glass of the steps on the other hand have interlayers of SG® SentryGlass, which is a stiffer interlayer material. The reason to have the steps realized with a stiffer material is because the glass layers in the steps are loaded perpendicular to the sheets. Therefore they need to be stiffer and have better adhesion.

SG interlayers perform better in warmer humid climates then the PVB interlayers. Adding to that the column and rail are also heat soaked as these are detrimental to the safety of the stairs and thus are in no way allowed to fail unexpectedly.

Unfortunately, due to financial limitations, the stairs could not be test loaded in place, instead calculations had to do. The downside to this was that the model could not give a decisive answer whether the stairs would be able to withstand impact loads. In this case, it is an advantage that the stairs is located in a spa as the risk of impact loads is small, except when moving appliances. Therefore, it was agreed upon that the stairs could only be used by persons and not for transportation of appliances. This was not a problem due to the presence of a second stairs in the building. A SCIA model of the entire structure was made to check the deflections and the overall load transfer within the system under the expected loading. The L-shaped beams to support the handrail were dimensioned according to the resultant forces on the end of the steps.

The most important part of the stairs are the connections. Other firms where reluctant to share their knowledge regarding the design of details in fully glass stairs. Therefore it was of great importance that these details where calculated and designed with great precision. The connections details therefore all were individually calculated using RFEM, software in which they could model the connections accurately and use the boundary conditions derived from the SCIA model.

The connections are the only part of the structure that is not made of glass, steel is used instead.
Almost all the connections were drawn inhouse, because there is only a small amount of standard connections available for glass stairs. The one standard available connections, was also one of the most important details, namely the step connection. The German company Pauli that is specialized in glass connections had one connection type available designed especially for stairs. In *Figure 2,* a connection designed by Pauli can be seen.

The connection on inside of the stairs, was the most critical one, as the surface area is the smallest, and therefore the stresses the highest. To lower peak stresses a flexible mortar was injected between the bolt and the glass. This mortar is specially designed so that it is flexible and see-through. The mortar is even composed in such a way that it has the

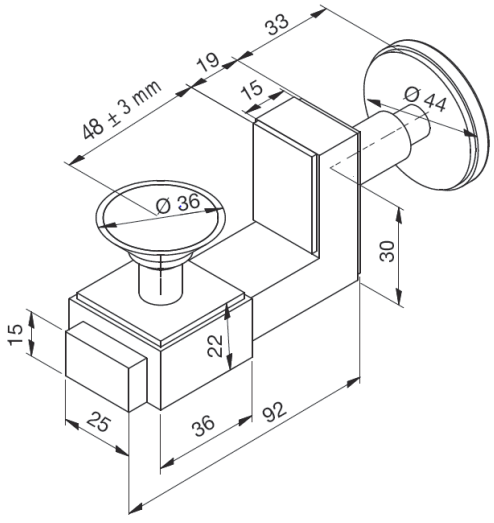

Figure 2: The connection of the stairs

same refraction index as the glass, and therefore becoming near invisible once cured. The application of this mortar is a specialized task, Hilti, the company that supplied the mortar, had to inject it themselves. The process of this injection is as follows: two small holes are drilled in the bolt, one of diameter 6 millimeter and one of 3 millimeters, after which the mortar is injected in the 6 millimeter hole while the 3 millimeter hole is used a venting hole. Since the connections can only handle the peak stresses after the mortar is injected, the stairs must be temporary supported during the construction. Once the mortar is hardened, the props could be removed.

Between the glass and the steel element a final stress relieving element is placed in the form of POM-rubber contact pads. Since the steps are mostly loaded in bending, the softening caused by the rubber in the connection is needed otherwise the peak stresses occur around the tipping point, which on its turn would be fatal for the

Figure 3: Two steps temporarily made of wood

structure. On the other hand, the steps all are calculated such that even if one of the layers would fail, the stairs would not collapse. In addition, people are careful when they see a broken layer. Thus, the step in question would not be maximum loaded anymore, and it can be replaced before it would fail completely.

In conclusion when the stairs is used in a normal way, the expected life time should not be less than a stairs made of any other regular building material. Therefore they expect the stairs to last at least 50 years. In *Figure 3,* the stairs just after completion can be seen. In this photo, two steps made of wood. Those steps had some surface damage which however most likely happened during installation or transportation where impact loads are more likely to occur. With the intended normal use of the stairs this should not happen, which is also the case ever since 2012, after the stairs was completed, no steps have failed. ◀

Figures:

Header	*Verhoeven & Leenders*
1	*Verhoeven & Leenders*
2	*Pauli + Sohn GmbH*
3	*Verhoeven & Leenders*