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Structural Glass Columns in a World War II German Hangar

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Abstract

In the woods / heather fields north of Arnhem (NL) the German invaders built in 1941 a complete new airfield called Deelen. To allow the airplanes being driven into the maintenance hangars an ingenious wooden roof structure was developed that enabled the complete front wall of the hangar building to be removed. After the World War II this hangar functioned as a storage room for potatoes. Maintenance was minimal resulting in 2010 in a seriously endangered condition of this building. In the meantime the buildings of the old airfield were declared historic monuments. Minimal repairs were undertaken, one of them being the reduction of the roof span of 23 meter by two big steel supports in three parts. The building is now developed to be a centre for small cultural activities. To reduce the big temporarily steel support frames to a functional, and visible, minimum we suggested to replace them by glass columns. We had experimented with glass structures at the Delft University of Technology. Study lead to a bundled column of massive borosilicate glass bars, diameter 30 mm, all glued together in a bundle with a length of about 3.5 meter. Two glass columns, one with a square cross section and one with a hexagonal cross section, were produced by the firm G&SS. Both glass columns were tested in the Stevin laboratory of the University of Technology. The two glass columns could easily carry the maximum safety load of the roof of the old hangar. So they were certificated by the University in short report. In the summer of 2026 the two glass columns will be installed in monument.

Keywords

Glass, Column, Load test, Monument.

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1. The history of the WO II hangar

In May 1940 Nazi Germany conquered the Netherlands. They were well prepared for the same month a long row of army trucks arrived in the area north of Arnhem to build an complete airfield and the world's first continental radar system. In the trucks arrived also the building materials for a hangar intended for the maintenance of the fighter airplanes. The trucks held a prefabricated wooden roof in parts to be assembled on site. It was chosen to give the hangar the appearances of a farmhouse to misled the Allied observers in the air. The roof is a brilliant design of the German engineers and an illustration of the craftmanship of the German carpenters. With only timber beams of 80 X 200 mm they created the complete roof structure. The most intriguing roof element is the central truss in the longitudinal axis of the roof that enables airplanes to drive through the completely opened up façade. The opening of the facade was made possible by an ingenious set of sliding/ folding doors, also disguised as the wall of a farm. The roof on this side had a span of about 23 meters. To realise this big span not one truss was realised but four trusses were placed next to each other. On the outside these four trusses were cladded by diagonally placed planks for extra stiffness.

Fig. 1. The old hangar on a misty winter day in 2020.
The front wall (now bricks and small windows) was originally a removable façade with sliding and folding doors.

After World War II this "farm"-hangar functioned for more than sixty years as a potato storage room. For this functional use the openable façade was removed and replaced by a massive brick wall with windows and a large door as can be seen in figure 1. Maintenance was however poor and slowly the building decayed. Around 2000 the whole area of the formerly German airfield Deelen was declared historical national monument. For whatever remained of it, a lot of buildings and airfield facilities were already dismantled. The problem with monuments is that the buildings will be preserved but how to exploit them properly is another story. For the hangar small cultural activities, like art exhibitions, theatre and musical performances, were organised but what about the deplorable condition of the hangar? The owner of the building, the municipality of Arnhem, came into action but only temporarily measurements were made. The ceramic tiles of the leaking roof were replaced by steel roof panels (ugly!) and the 23 meter span of the roof was divided by two temporarily steel supports in three times about 8 meter span. This reduced the stresses in the big central truss enormously by a factor 9! With these cheap adjustments the structure was considered to safe for use by people for cultural activities.

It is certainly clear, as can be seen in figure 2, that this "beautiful " steel supports are not practical to say the least. Therefore the main author suggested to replace them by two glass columns.

Fig. 2. The two temporarily steel support structures (in red) in the hangar during an exhibition about bio-based building materials.

2. Development of a structural and safe glass column

It is an old dream of the main author to create a structural, and safe!, glass column in a real, public building. In his book "Glass in structures" (Nijsse, 2003) various possibilities for safe glass columns were described . With architect OMA around the year 2000 two projects were studied on to have glass columns installed, a museum in Seoul, Korea, and a villa in the Netherlands. Unfortunately due to economic circumstances, Seoul, and a client who hated delay due to the fact that a steel façade column was to be replaced by a glass one, the Netherlands, these projects never had their innovative glass columns.

When you mention the possible use of an all glass column to a client his or her first reaction will be: An all glass column in my project? Are you nuts, glass can break so easily, everybody knows that!!!

We therefore teach the students that all glass elements of a structure must be able to deal safely, without complete collapse, with an attack by a madman or madwoman with a sledgehammer. If you can explain why you are convinced that the madman attack can be dealt with (in a reasonable time of course) you have worked out a good and safe design. The overall answer to this madman challenge is not to make one structural glass element but a number of them. So the madman can smash one, two etc. before you can stop him but the glass structure will remain intact.

What kind of glass elements are available for our safe glass columns? Basically three; flat panels, massive glass bars and glass cylinders. We developed three major strategies to create a safe and beautiful all glass column, see figure 3.

- Strategy 1: The bundle of massive glass bars.
- Strategy 2: the layered glass cylinders.
- Strategy 3: a number of glass panels.

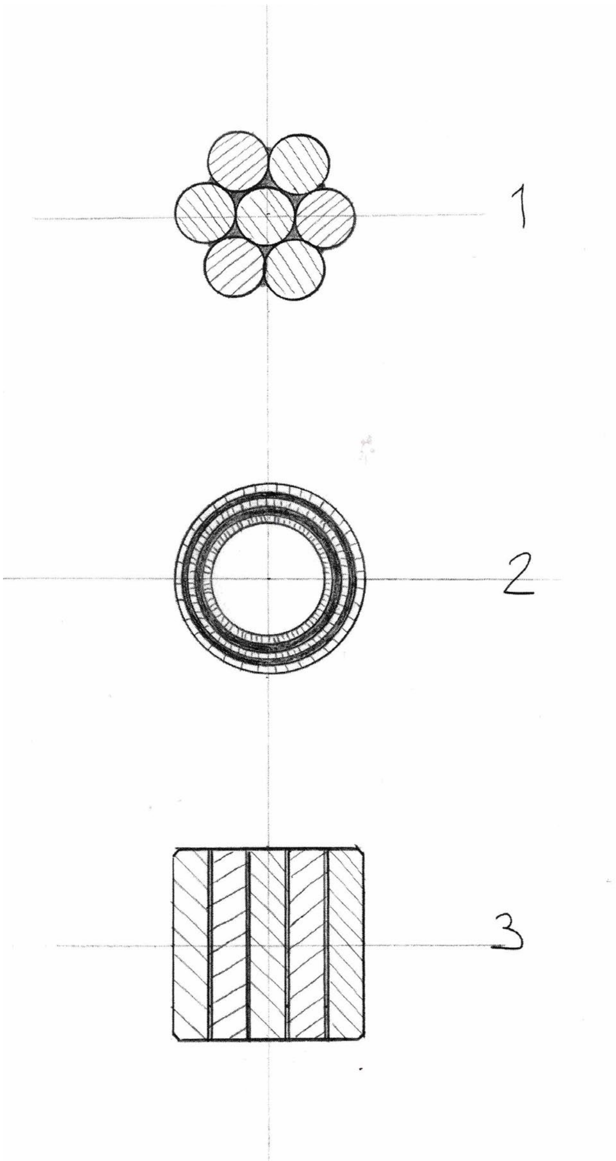

Fig. 3. Three different strategies to create a safe all glass column.

Of course all glass parts have to be clued together carefully to create a combined cross section with an high as possible moment of Inertia. Especially to create an high as possible buckling resistance.

To be able to resist the madman with a sledgehammer we have to increase the number of glass elements, bars, cylinders and panels, dramatically. Safety is in large numbers.

Regarding fire resistance; glass bars and glass cylinders have an already good fire resistance being made from borosilicate glass. Flat soda-lime-silicate glass panels have a much lower fire resistance. However, since fire resistance tests on glass columns are still unknown, for the time being glass columns may not be part of a robust main structure concerning structural safety.

After ample considerations we chose for this German hangar for the bundle column concept. Since we needed two columns, and regarding buckling we also needed a symmetric cross section, we chose for a square and a hexagonal glass bundle column.

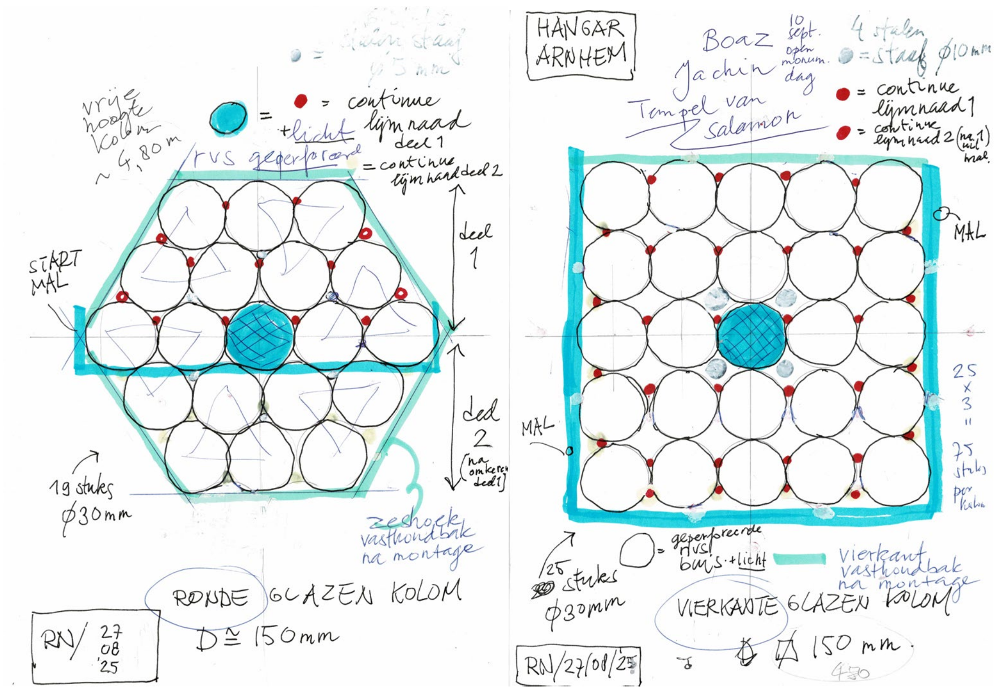

Fig. 4. The two sketched concepts for an all glass columns, the hexagonal and the square one.

We also worked out the gluing patron to build up this bundled columns. The sequence is worked out in the two sketches in figure 4. One secret has to be revealed we inserted one stainless steel bar in the centre with the same diameter as the glass bars of the bundle column. This was done for two reasons. Reason one: to connect the all glass column to the top and the bottom steel footing elements to make a firm connection with this steel bar and reason two: to be able to take up possible tensile forces on the glass column. It is surprising to see in the realised glass columns that this central steel bar is almost invisible!

The next details to be worked out were the top and bottom steel footings of the glass bundle columns. We chose for steel footings where the glass columns were glued in with Hilti mortar.

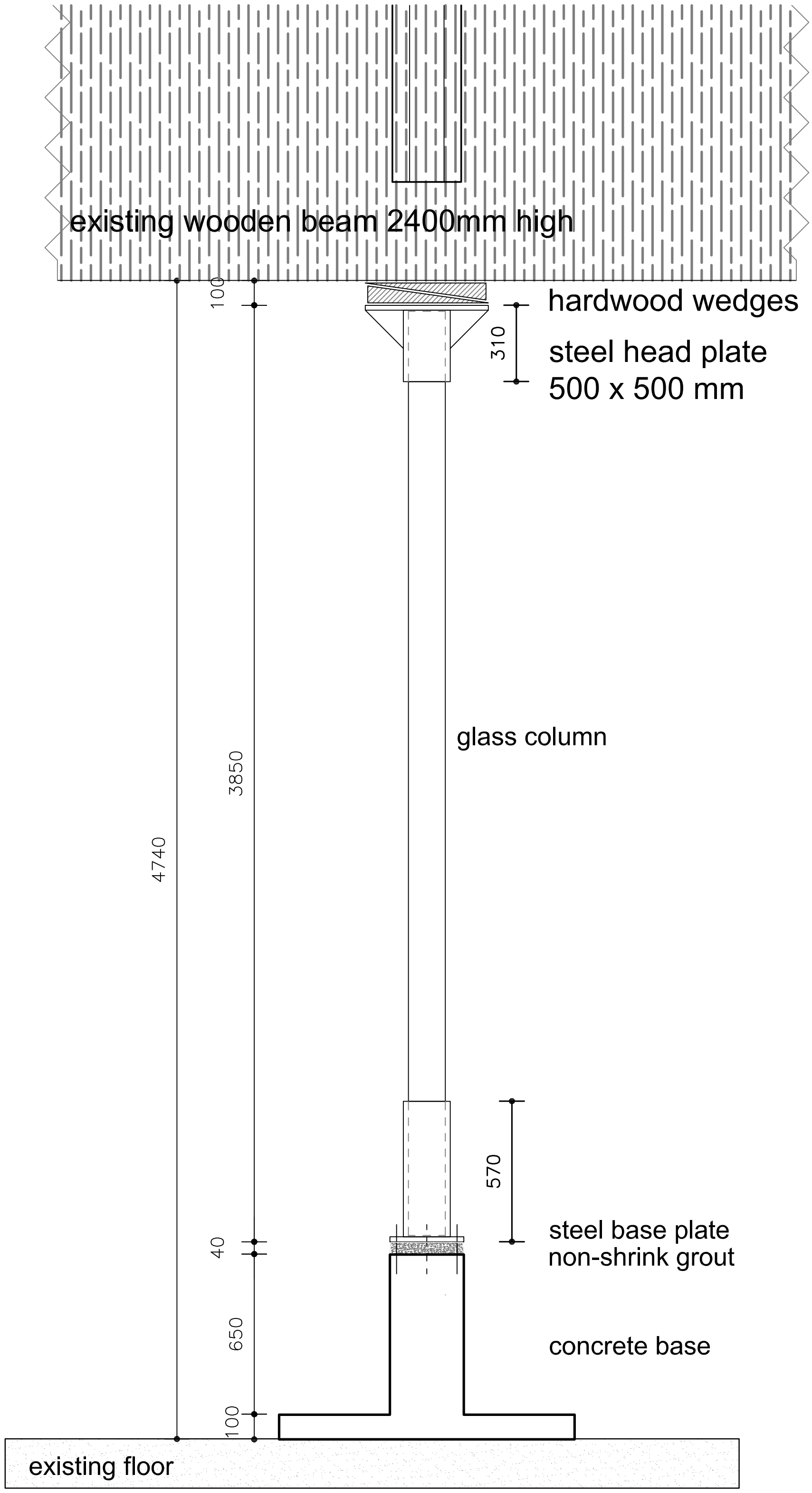

Fig. 5. Overview of the glass bundle column.

The glass columns were produced in Rotterdam by G&SS, Marc Klein, in the workshop. This was a complicated and careful job. Schott AG delivered the massive boro-silicate glass bars, diameter 30 mm in standard lengths of 1500 mm. Since we needed a column of 3540 mm for the situation in the former hangar we had to combine a lot of bars in the bundle concept. Decided was to put an aluminium disc in the contact between two massive glass bars on top of each other. To increase coherence in the bundle column the positions of these aluminium joints plates were alternating. It took three weeks to clue the columns carefully together making every glass bar as fitting as possible to his neighbour bars. After putting the glass columns in a protective wooden casing they were transported to the Stevin lab of the Delft University of Technology.

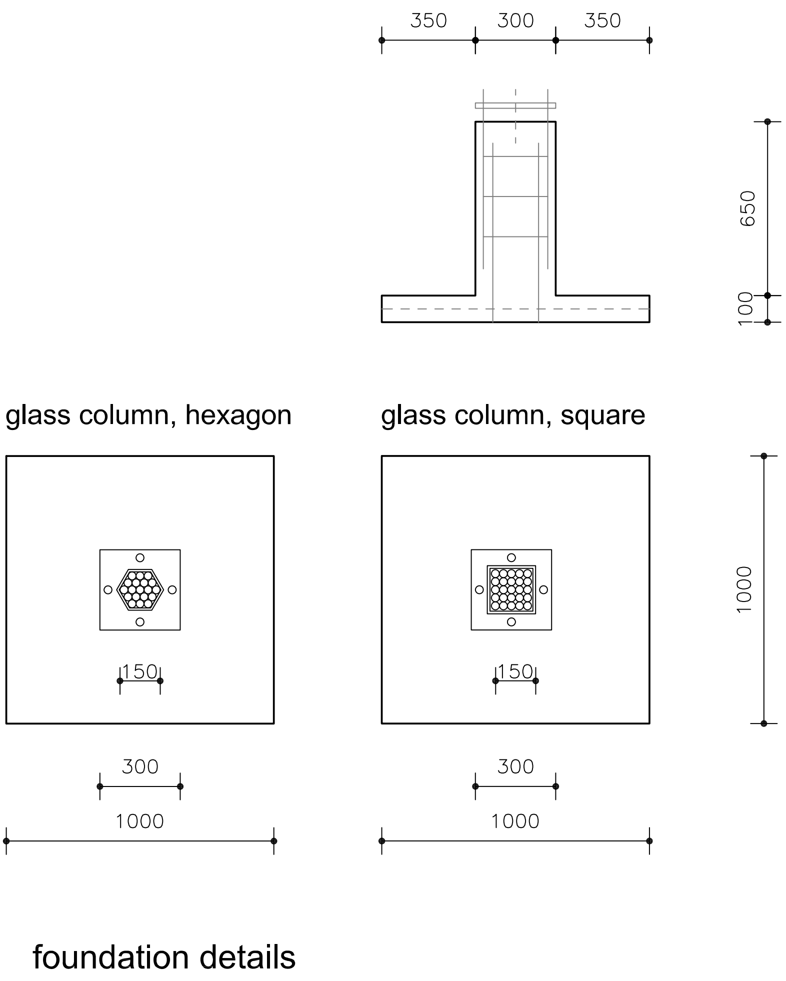

Fig. 6. The foot detail of the glass bundle columns.

With the aid of the overhead crane of the Stevin laboratory the two steel connections were attached to the ends of each glass column. An ingenious system of holes in the steel elements allowed the perfect filling of the area between the glass and steel with the Hilti mortar. In the days after this assembling the square and the hexagonal glass columns were tested in the Stevin laboratory. These tests are described in another chapter.

Fig. 7. Production of the hexagonal glass column in the workshop of G&SS in Rotterdam.

3. Calculation of the forces in the glass columns and control of their buckling behaviour

To know the axial forces in the glass columns a structural model was developed. With this model, loaded with the dead load and the, required by the Standards, live load on the roof, the axial forces in the two temporarily support structures were calculated. On all types of load the usual safety factors were applied. It was calculated that the ultimate axial force in the supports was 140 kN.

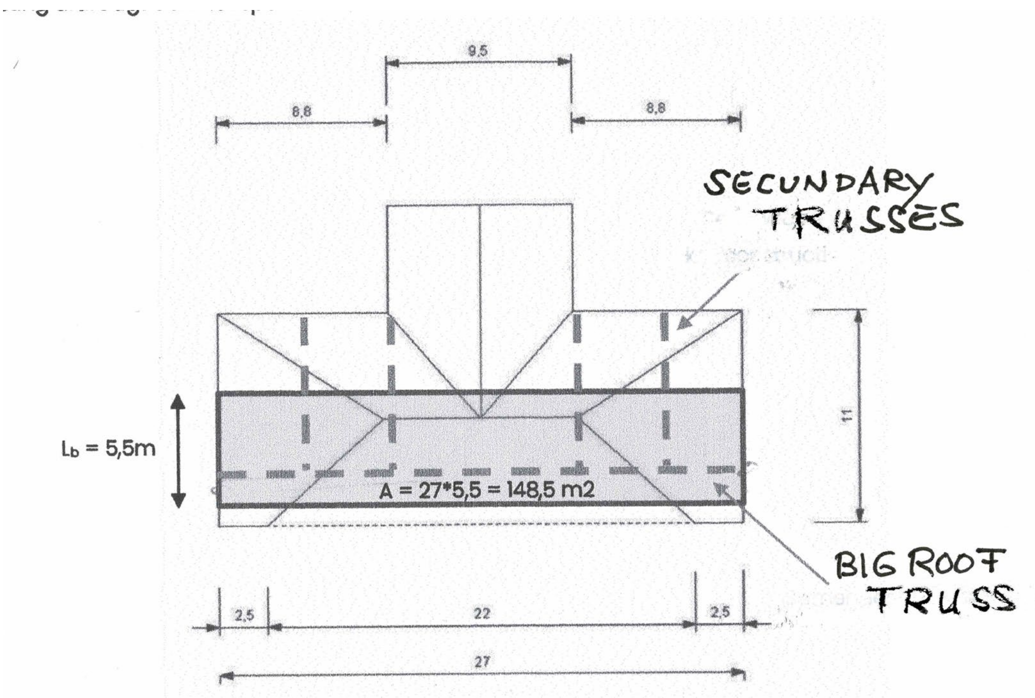

Fig. 8. Plan of the roof structure of the hangar.

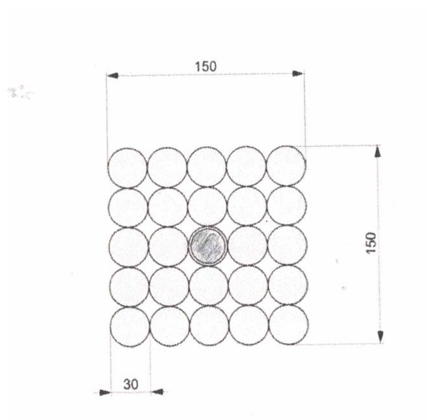

Fig. 9. Cross section of the square glass column.

3.1. Control of the square glass column

The moment of Inertia of this complicated cross section was calculated by the program Rhinoceros. The actual length of the column is 4310 mm. The Euler buckling load of the square column was calculated to be 1216 kN. The (extra) buckling safety is there for 1216/140: a factor 8.6.

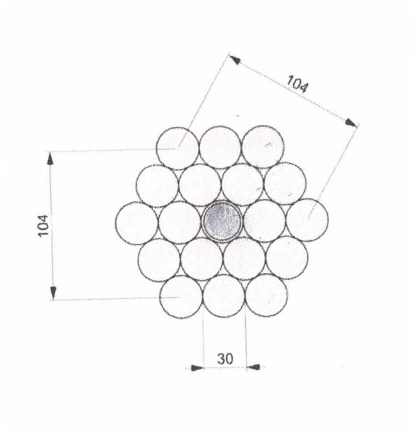

Fig. 10. Cross section of the hexagonal glass column.

3.2. Control of the hexagonal glass column

The moment of Inertia of this complicated cross section was also calculated by the program Rhinoceros. The actual length of the column is 4310 mm. The Euler buckling load of the hexagonal column was calculated to be 591 kN. The (extra) buckling safety is there for 591/140: a factor 4.2.

This is all very well but remains paper work. Words, numbers and not plain facts. There for G&SS has the strategy to test each new glass structure on strength in the Stevin lab in Delft. This is the ultimate proof of the real structural capacity. We tested both glass columns, the square and the hexagonal, to a maximum load of 250 kN. This load was maintained for 5 minutes. We know after these tests that the capacity of glass columns itself is sufficient for use in the old German hangar (and could prove this to the critical Municipality of Arnhem!).

Fig. 11. Testing of the hexagonal glass column in the Stevin lab in Delft.

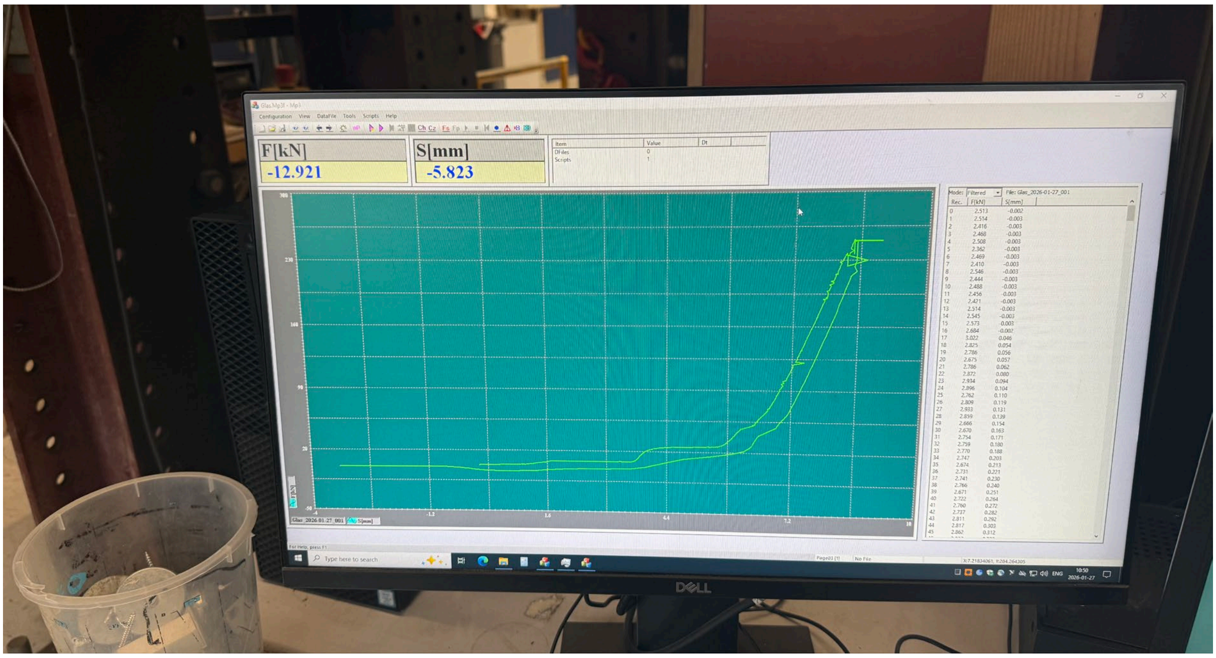

Fig. 12. Screen shot of the testing of the hexagonal glass column in Delft.

3.3. Execution of the transfer from the steel support frames to the new glass columns

A problem to be solved was how to take the original steel supports away and replace them, safely!, for the two glass columns.

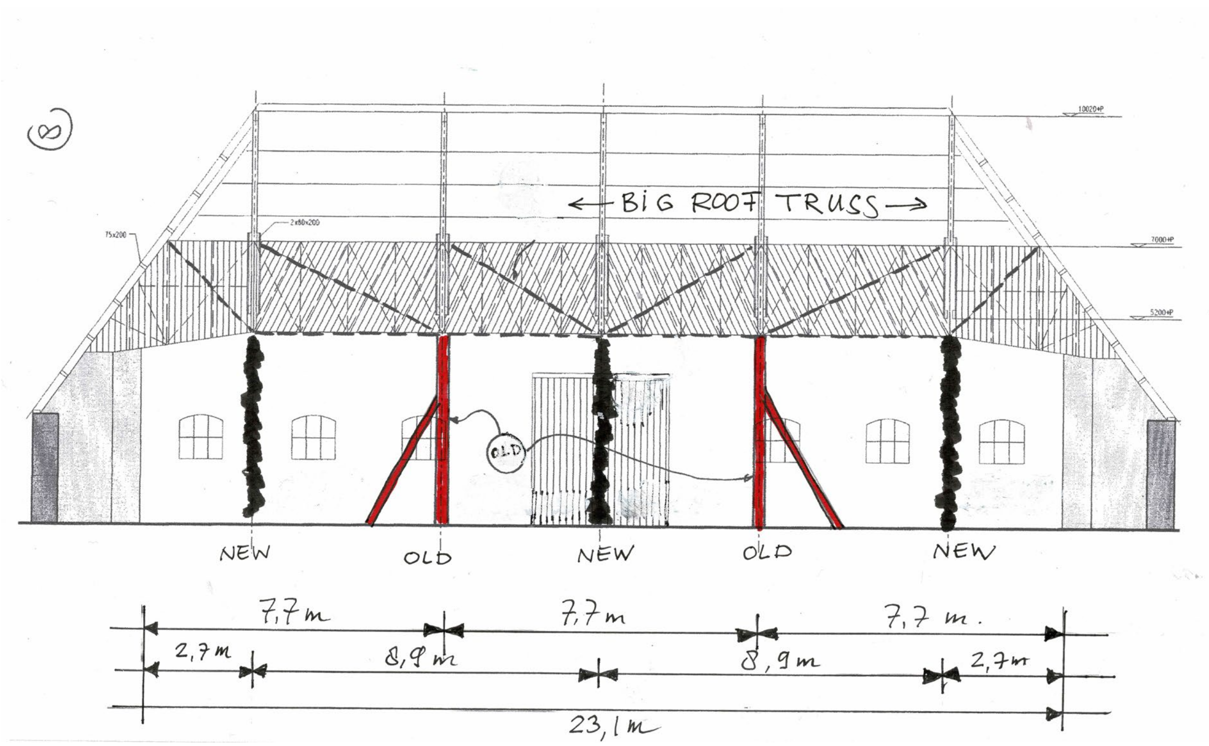

Fig. 13. The new temporarily supports for the replacement of the old supports by the glass columns.

Fig. 14. The square glass column has arrived in the old German hangar.

4. Report situation halfway April 2026

The old German hangar is a historic monument and lies in a national park the Hoge Veluwe. This makes it a location where a lot of civil servants have to protect their responsibilities. The interests of Nature were increased by a pair of barn owls that choose to make a successful nest in the hangar. Civil servants insisted on the careful treatment of these birds. The monument people demanded a careful reconstruction of the very interesting roof structure of the hangar. The owner of the hangar, the municipality of Arnhem, had no money to take care of these complicated operations. A check mate situation resulted and the two glass columns, tested and all, were waiting in the Hangar, see figure 14. After a lot of discussion this Gordian knot was unravelled by the decision that the building team was allowed to ask building permit to replace the temporarily steel supports by temporarily glass supports. And of course take care of adequate breeding possibilities for the barn owls. The paper work is now on its way to the authorities and we have good hope that all noses are now turned in the right direction.

We hope to realise at least this year 2026 the situation shown in figure 15 and hope to start cultural activities in this very special building. Time will tell!

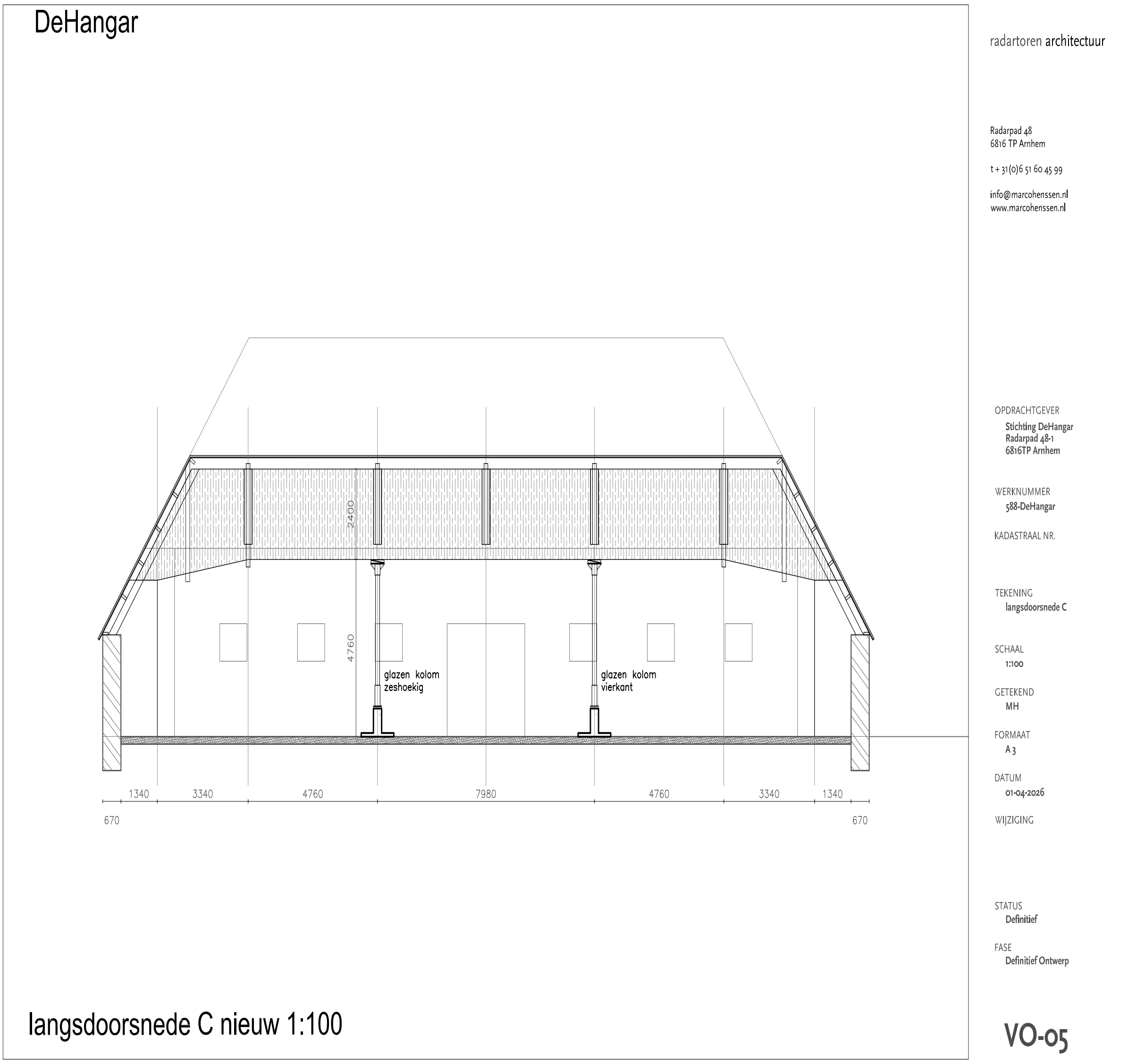

Fig. 15. Longitudinal cross section of the hangar with the two new, temporarily, glass columns.

Acknowledgements

- Owner of the hangar: the Municipality of Arnhem (NL).
- User of the building: Stichting De Hangar at Arnhem (NL)
- Structural design and calculations: ENS engineers at Delft (NL).
- Testing of the glass columns: Stevin laboratory in Delft.
- Production of the two glass columns: G&SS at Rotterdam (NL).
- Producer of the massive glass bars: Schott at Mainz (D).
- Installing the glass columns: G&SS, Rotterdam (NL) and Schaart Adventures, Velp (NL).
- Architectural elaboration of architectural detailing: Marco Henssen of Radartoren architectuur

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