Hovenring – when Designers and Structural Engineers join forces

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SUMMARY

This paper is all about the inspirational design of the Hovenring, a circular cable-stayed bridge in Eindhoven, the Netherlands. It’s a perfect example of what can be achieved when designers and structural engineers truly join forces. Many elements of the bridge’s structure were custom made to fit the initial design concept as conceived by bridge design office ipv Delft. Several significant issues had to be dealt with during the design and engineering phase, such as spatial integration and user comfort, and the structural concept especially required an open mind and a lot of calculations. Furthermore, there was the issue of wind-induced vibration, that caused the bridge to be closed off only weeks after it had been put in place. And a lot of thought and effort went into important details such as cable anchorage as well as the lighting design. The close collaboration between designers, engineers and other parties involved paid off, as the final result has received worldwide appraisal and couldn’t be more powerful.

Keywords

Aesthetics; spatial integration; structural concepts; wind-induced vibration; dampers; collaboration; cable-stayed; lighting design.

1. INTRODUCTION

In the summer of 2012, the Hovenring, a circular cable-stayed cycle and pedestrian bridge in the Dutch city of Eindhoven was completed. With its 70-metre high steel pylon, 72-metre diameter deck and integrated lighting, the bridge is a new landmark for the city.

The Hovenring is a perfect example of what can be achieved when designers and structural engineers truly join forces. Many elements of the bridge’s structure were custom made to fit the initial design concept as conceived by bridge design office ipv Delft. Although this meant the design and build process was one of extensive discussions between designers and engineers, the final result certainly couldn’t be more powerful.

2. BACKGROUND

There had been an ordinary traffic roundabout right on the border between the cities of Eindhoven and Veldhoven for years. However, in 2008, with building work on a nearby new housing estate about to start, Eindhoven City Council knew it would only be a couple of years before the existing traffic intersection wouldn’t suffice anymore. Traffic would increase once the estate was completed and therefore, a revision of the intersection was necessary. Traffic lights seemed to be inevitable.

Traffic lights however would mean cyclists regularly had to stop and wait for minutes before they could continue their journey. And as Eindhoven City Council intended to increase both traffic flow and road safety for cyclists especially, a level crossing simply wasn't an option. In addition, Eindhoven as a rule refrains from cyclist underpasses as they often make cyclists and pedestrians feel unsafe at night. This left the council with a dilemma. They asked Dutch bridge specialist ipv Delft to look at possible solutions. Whatever the solution, it had to also clearly portray the intersection as an important entrance to Eindhoven, Veldhoven and the new Meerhoven estate. Furthermore, the intersection needed to become a new landmark for the city of Eindhoven, befitting both its identity as the City of Light and its motto 'Leading in technology'.

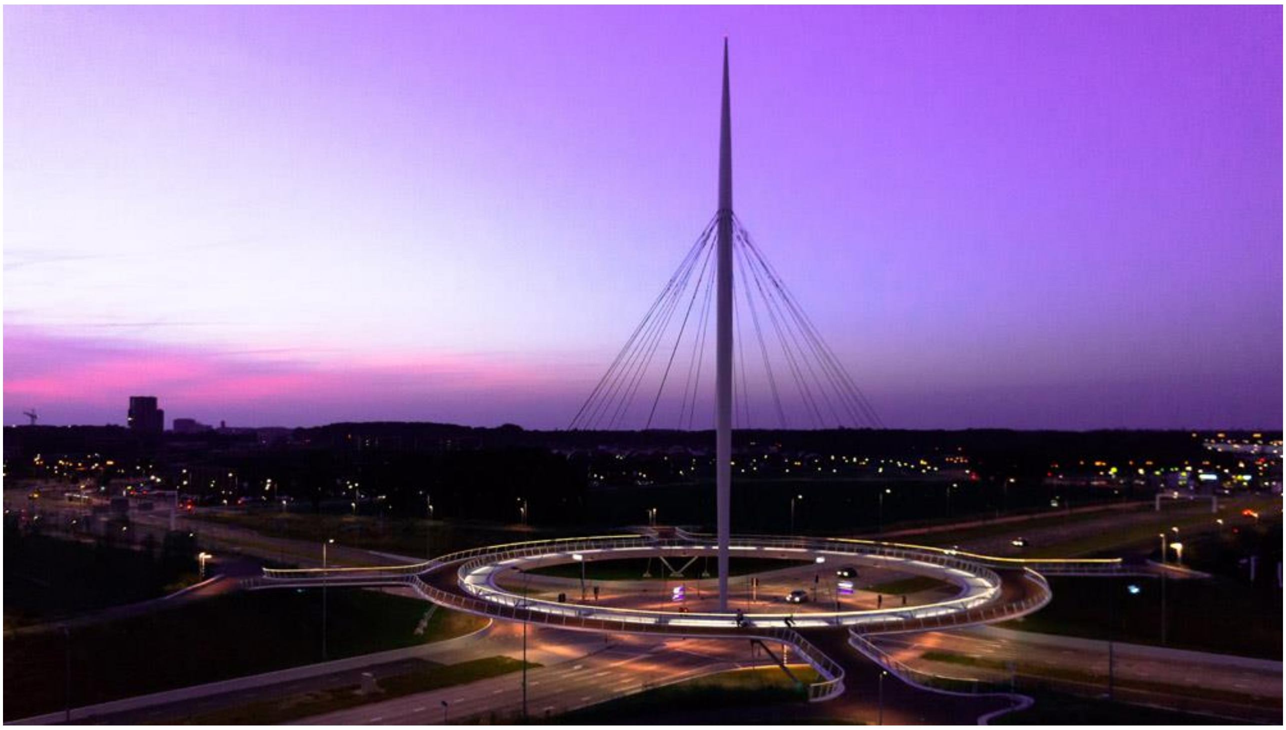


Fig.1 Aerial overview of the Hovenring by night

3. CONCEPTUAL PHASE

We were asked to look at the various options and costs. A circular cable-stayed cyclist roundabout soon appeared to be the best option. Several design concepts were then made, among which were a self-supporting circular bridge (which was structurally very inefficient due to the large amount of concrete or steel needed and the large self-weight), a steel single arch bridge with cables (which would be structurally inefficient, mainly because of the angle at which the cables had to be and the large horizontal loads that the steel arch would therefore have to withstand) and various cable-stayed bridges. Eventually, both city council and designers opted for the floating circular cable-stayed bridge with a single central pylon, as it was the most appealing design and it complied with the requirements on structural efficiency and costs. The most competitive alternative was a self supporting steel ring, which had similar costs, but lost to the pylon bridge when it came to appearance and structural efficiency. According to the city council, the preferred circular cable-stayed bridge was 'spectacular in its simplicity' and 'a natural landmark' that only needed careful and elegant detailing.

In appliance with what the client had requested, the combination of pylon and circular deck also fit in well with the existing landmarks of the city: the nearby Evoluon (a building shaped like a flying saucer), the Beukenlaan light needle (a 47 metre-high light sculpture) and the Floraplein fountain (an illuminated circular fountain).

The bridge will also become part of a new 32 km long cycling route connecting all economically most important sites around the city, the so-called Slowlane.

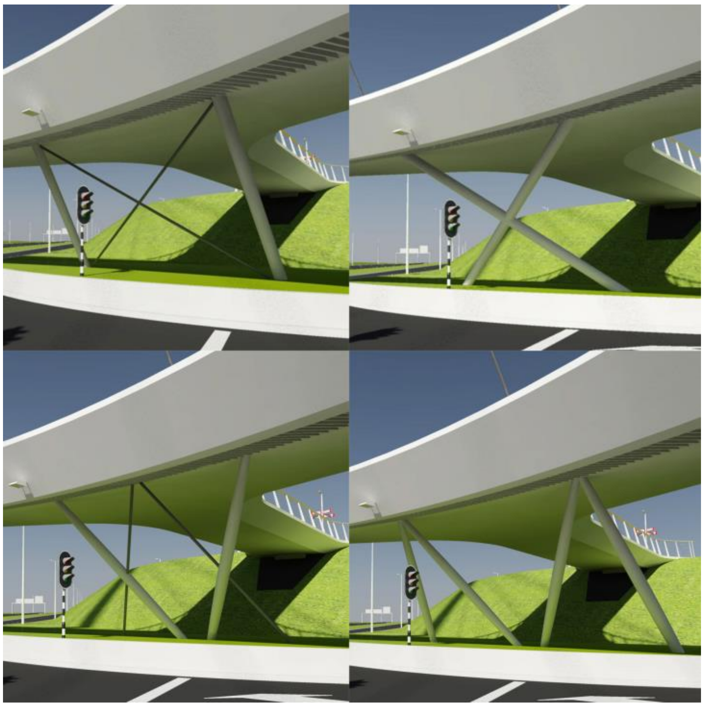
4. SPATIAL INTEGRATION

One of the challenges at the start of the design process was the spatial integration. Existing buildings limited the room available at ground level. At the same time, the necessary comfort for cyclist required a maximum grade, preferably around 2 %, which determined the amount of space needed for the ramps. The required space simply wasn't available. We therefore looked into different options for both the location and layout of the ramps, as well as for the grades. As in the Netherlands there are no clear regulations on desirable grades for cyclist slopes, the city council asked us to examine what grades would be comfortable still in this certain situation. We examined and measured some twenty slopes of similar bridges, and observed and interviewed cyclists and pedestrians. The entire project team also visited several sites by bicycle and we spoke to organizations representing the disabled. Based on all our research, we decided the only option that successfully allowed for comfortable slopes was to lower the ground level of the intersection underneath by a metre and a half. This resulted in 3 ramps with a slope of 2 to 2,2 percent, and one that is a still rather comfortable 3,1 percent.

5. STRUCTURAL DESIGN

Once basic design and spatial integration were decided on, it was time to tackle another major challenge, that of the structural engineering. The bridge comprises a 70-metre high steel pylon, 24 steel cables, a circular steel deck and a circular counterweight. The cables are attached to the inner side of the cyclist deck, right where it connects to the circular, concrete counter weight. This reduces torsional loading and twisting deformation of the 72-metre diameter deck. Apart from the common aspects, such as stability, rigidity and efficiency in use of materials, the aesthetics of the bridge also played a major role in the structural design. We had a very clear view of what the bridge should look like: little more than a thin circular bridge deck and a powerfully shaped pylon.

To carry he bridge's own weight, a very slim supporting structure would suffice. The cables are attached 8 metres centre to centre at the bridge deck segments' centre of gravity and carry the full load of the bridge's own weight. Concrete blocks inside both deck and counter weight ensure that each segment is balanced. The live load, however, does not apply to the centre of gravity only and therefore causes bending and twisting moments within the deck. In addition, the circular cable-stayed deck acts like a swing, the cables absorb vertical loads, but in doing so create a horizontal component. When the variable load is only present on one side of the ring, the bridge will not be balanced. A solution for this was needed. In the preliminary design, a number of cables continued all the way to ground level underneath the approach spans, with the approach spans functioning as struts. These continuing cables located near the approach spans offered stability to the pylon but not to the deck. The horizontal loads would have to be directed through the



approach spans towards the abutment. Combined with the envisioned slenderness of the approach spans, this meant the circular deck would deform too much in case the bridge is not equally loaded.

5.1 SUPPORTS

We then looked into the option of V-shaped wire struts underneath the bridge deck. The stiff triangular shape would be able to absorb the horizontal component of the variable load, but the vertical deformation of the bridge deck however remained unacceptable. Various other options were examined, and eventually we designed M-shaped supports.

Fig. 2 Various options for the design of the supports were examined

They have been placed at the same angle as the cables, which means the supports are a visual extension of the stay cables. The supports combine two compressive struts placed in a V-shape and two pre-stressed tension rods, thus forming an M-shaped rigid support. The main part of the variable load is transferred by the compressive struts rather than the steel cables hanging from the pylon. As a result, the amount of vertical deformation at the deck edges caused by variable load is significantly smaller.

In addition, the M-shaped supports have to carry a big part of the self-weight, due to the cables' deformation under load. The M-shaped supports also transfer horizontal loads, such as wind load. The tension rods have been pre-stressed in order to prevent them from sagging. The compression rods are solid steel, due to the significant compression forces they have to withstand combined with their relatively large length and the desire to make their shape similar to that of the cigar shaped pylon.

5.2 BRIDGE DECK

The bridge deck has a multi-cell box structure; with ribs welded onto both upper and bottom steel plate every 332 mm. This allows for the structure to be as slim as possible, and enables the deck to successfully withstand forces and deformation caused by non-uniform moving loads. This type of deck requires a large amount of welding, but has significant structural benefits. It improves torsional stiffness and activates the bottom face in local and global bending, significantly reducing material use.

6. VIBRATION

With any steel structure such as the Hovenring, comes the issue of vibration. This played an important part in the engineering of the bridge. The two main forms of vibration to beware are vibration of the bridge deck, mainly important because of user comfort, and wind induced cable vibration.

6.1 BRIDGE DECK VIBRATION

Analysis of the bridge's natural frequencies and possible vibrations of the structure as a whole showed the natural frequency of the bridge was within the range where pedestrians jumping up and down could cause uncomfortable vibration. We considered two possible solutions, applying dampers and increasing the self-weight of the bridge and eventually decided on the latter. One of the main reasons to not choose a damper system, is the fact that such a system requires regular adjusting and maintenance. Given the slenderness of the structure, a damper system would require access hatches and those would be harmful to the desired appearance.

The self-weight of the bridge deck was increased by partly filling it with concrete. As the structural dimensions are mainly dependant on the stiffness in carrying live loads and not so much dependant on the balanced self-weight, adding concrete only had a minor influence on the deck's structural dimensions. Increasing the minimum self-weight of the deck to 500 kg/m2 has shown to be an effective way to make the system unresponsive to user-induced vibration. This effect was clearly visible during construction. Vibrations caused by building activities appeared a lot stronger in segments without added concrete compared to those where concrete had already been added.

6.2 **WIND INDUCED VIBRATION**

Predicting whether or not wind induced vibration will occur is very difficult and results of theoretical analysis often prove to be untrustworthy. In close collaboration with the client, we therefore decided early on that we would only apply vibration dampers to the steel cables if they would prove to be necessary. A couple of weeks after the pylon and stay cables were put in place, the cables started vibrating heavily. Professor A. Zasso from Milan, an expert on vibration in cable stayed structures, was asked to examine causes and solutions. The natural frequencies and actual damping values of the structure were measured and a system of custom made tuned mass dampers was designed. The system comprises two dampers for each cable. A low frequency damper and a higher frequency damper, placed at 10 and 3,5 metres respectively from where the cables are attached to the pylon. Wind induced vibration has not occurred since the dampers were put in place.

Fig.3 An example of the type of damper used.

7. COLLISION LOAD

Predicting the exact effects of an accidental collision is virtually impossible. The compartmentalized cross-section of the bridge deck however means local damage caused by the collision impact will only have a local effect on the structure’s load bearing ability. A collision therefore will not cause the Hovenring to collapse. However, there is a risk of the bridge being damaged in such a manner that it can no longer be used. To make sure this won’t occur, we designed a freestanding structure to support overhead road signs that also functions as anti-collision portal as their vertical clearance lies below that of the Hovenring itself. The portals are designed to withstand collision loads. Furthermore, in case they are damaged by an accidental collision, the portals will be much easier to replace or repair than the bridge, and at a much lower cost. The bridge will not have to be closed off in case of a collision either.

Fig. 4 Anti-collision portal

While the bridge deck isn't designed to withstand collision loads, the concrete barriers around the pylon foot, the pylon itself and the concrete barriers near the supports have to be able to successfully withstand forces caused by vehicle collision. In order to prevent serious damage to the bridge in case of a collision, the bottom section of the pylon is filled with concrete.

8. CABLE ANCHORAGE

During the entire design and construction phase, we spent a lot of time figuring out the most efficient and aesthetical details. One of the areas that specifically needed a lot of attention, was the anchorage of the stay cables to the pylon. The standard anchorage with gusset plates and fork sockets would result in a bulk of steel near the pylon top, which of course would detract from the bridge's appearance and was therefore unwanted. We looked into several other possibilities, such as anchors inside the pylon, and eventually chose to use conical sockets which are partially placed inside the pylon. As room was limited on the pylon surface, the stay cables have been attached in two separate rows, allowing room for anchorage inspection inside the pylon. A hatch just above the cable anchorage provides access to an internal platform from which the anchors can be reached. It is also possible to carry out remote inspections by camera from within the pylon.

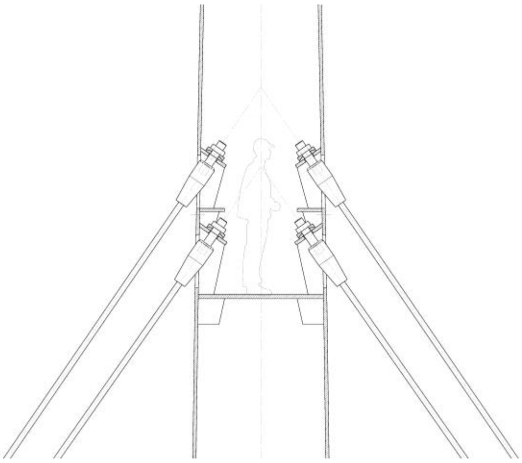


Fig. 5 Cable anchorage at pylon top

A similar method was used to attach the cables to the bridge deck. Here we designed a tailor made cover that ensures a watertight anchorage. The anchors are accessible through a hatch on the deck's bottom side.

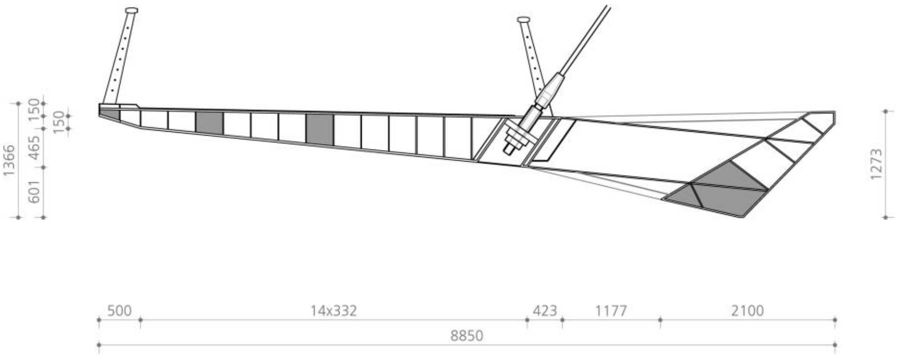


Fig. 6 Bridge deck cross-section, with cable anchorage and added concrete visible

9. LIGHTING DESIGN

Befitting Eindhovens identity as The City of Light (the city is home to light bulb manufacturer Philips), we also put a lot of effort into the integrated lighting design. One of the main elements is the lighting within the circular deck, in the space in between bridge deck and counter weight. Both top and bottom of this in between space is fitted with aluminium lamellas and translucent sheeting and the tube lighting inside creates a surface of light. At night, this ring of light plays a substantial role in the Hovenrings appearance, reinforcing Eindhovens City of Light identity.

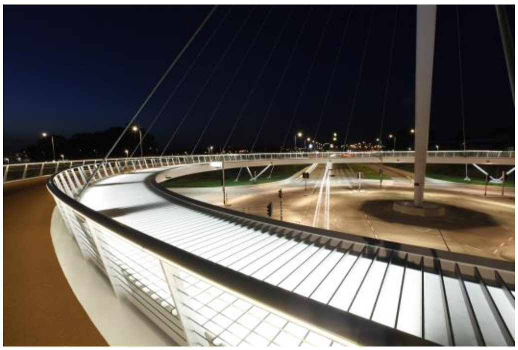


Fig. 7 Ring of light as seen by pedestrians

Fig. 8 Ring of light as seen by traffic underneath

Functional lighting for the traffic intersection underneath the cyclist fly-over is attached to horizontally placed steel wires in the area in between pylon and circular deck. Eight suspended light fixtures and twelve light fixtures attached to the inner side of the counter weight together create the required amount of light. The spider web like net of wires is only attached to the bridge deck, not to the pylon itself.

LED lighting integrated into the railings, creates a secondary, subtler ring of light. We used two types of LED lighting. Particularly bright LEDs illuminate the bridge deck, and less bright LEDs are used to illuminate the bridge users, thus ensuring facial recognition and a feeling of safety. The required cabling is fitted inside a handrail, which we developed together with Philips. It is a custom made aluminium extrusion profile that offers space for cabling, mounting and both types of LEDs.

The pylon is also carefully illuminated. Uplighters placed on ground level illuminate the pylon from the bottom on up, while its upper section is illuminated by lighting attached to the outside of the roundabout. Both types of light fixtures have been fitted with tailor made grills to prevent blinding and to ensure the light only illuminates what needs to be illuminated.

A red light at the top of the pylon was required given the presence of the nearby Eindhoven airport.

10. CONSTRUCTION

The structure itself and the desired construction time meant the Hovenring was a rather big challenge for the structural steel contractor. They created a comic book like document that showed the entire construction in 3D, allowing them to check whether steel workers would be able to reach all necessary welds.

Both counterweight and bridge deck were each constructed at the steel contractors factory in Belgium in twelve different 16 metre-length sections and then transported to Eindhoven by boat. The same goes for the four approach spans. On site, all sections were assembled on temporary supports and then welded together. To save time, all sections were welded simultaneously by several groups of steel workers.

The pylon was transported to the Hovenring site in two sections, which were welded together whilst lying horizontally underneath the circular deck. At that time, the deck was already fully assembled, which meant the pylon could be anchored to the circular deck and its M-shaped supports right away, after which the temporary supports could be removed.

Fig. 9 Construction work on erecting the pylon

11. APPRECIATION

Ever since the Hovenring was opened to the public in the summer of 2012, international media coverage has been overwhelming. The bridge has been praised for its design and the city council has been praised for having the guts to put cyclists and their needs before that of motorists. The Hovenring has been visited by many international pro-cyclist delegations in the past year.

12. DISCUSSION AND CONCLUSION

The Hovenring could have easily looked very different. It’s appearance is the result of close collaboration between designers, engineers, urban planners, client, interest groups and other parties involved. The key to getting such a result, one that not only satisfies the needs of all parties involved but also goes above and beyond initial expectations, is an all-encompassing collaboration.

This requires good leadership, but it also requires all parties to:

1) be convinced of each other’s added value

2) listen carefully to and be interested in each other’s intentions and motivation

3) acknowledge that other parties can indeed have good ideas regarding someone else‘s field of expertise too

As for the Hovenring's design and engineering process, Eindhoven City Council luckily was very aware of the conditions needed for successful and fruitful collaboration. This allowed us to come up with things that went beyond common design practice. For some parties involved the all-encompassing approach to close collaboration took some adjusting. When things got tough, for instance, they tended to opt for the standard solution. But because of the all-encompassing approach, we always came up with the most suitable solution in the end. If we had taken the easy way out and chose to follow common engineering practice when it came to such complex and defying aspects as cable anchorage, supports and lighting, the final result would have been much less appealing.